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TEACHING VOLUNTARY HANDWARMING FOR THE PROMOTION OF HAND EFFICIENCY AT COLD TEMPERATURES

by

© ALLAN W. HAYDUK

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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FACULTY OF GRADUATE STUDIES AND RESEARCH

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to my experimental subjects:

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ABSTRACT

The prolonged exposure of hands to cold environments leads to substantial cold pain and severe deterioration of manual dexterity, finger dexterity, hand strength, and tactile sensitivity. This study taught volunteers to warm their hands at -14 degrees Celsius and measured the effects on these hand efficiency variables. The subjects were eight male and female non-smoking volunteers. All research was conducted in a cold chamber during the warm summer months to eliminate seasonal factors.

A combined multiple baseline/ABA single subject design with multiple replications was used. Each subject's hand performance was obtained for both hands in the warm and in the cold. One hand was trained and both hands were re-tested in the cold. The second hand was trained and both hands were re-tested in the cold. Finally, the subject inhibited warming while in the cold (treatment removal) and both hands were tested again.

The treatment itself used biofeedback instrumentation to extend and enlarge previously classically conditioned vasodilative episodes. The procedure was found to be effective for bringing about temperature changes in the cold. Large treatment effects were found on all hand efficiency measures. The results suggest wide workplace and theory implications.

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1. INTRODUCTION

1.1 Overview

The primary purpose of this study was to investigate the effect of voluntary hand warming upon hand efficiency in cold ambient temperatures. All subjects received an instructional treatment package designed to teach them to induce and maintain voluntary hand vasodilation during the concurrent performance of a complex motor task in both normal and cold ambient temperatures. Measures of manual dexterity, finger dexterity, hand strength, tactile sensitivity, and degree of cold-induced pain were taken in a standard cold setting and then compared tc performance on the same measures after training. A multiple baseline experimental design was employed.

This chapter begins with an introduction to the debilitating effect of severe cold on hand efficiency. The notion that voluntary control may be obtained over hand temperature is discussed next. The chapter closes with a statement of the rationale underlying the study, namely that, in cold settings indirect control over hand efficiency may be achieved by teaching people to redirect metabolically produced heat to their hands.

Chapter Two, 'Man In The Cold', reviews mankind's physiological mechanisms for dealing with cold. Although the emphasis is on hand mechanisms, a brief discussion of whole-body survival mechanisms is also provided. The

sequence of physiological changes which take place following months, years, or generations of cold survival is discussed and suggested as a model for the present study. Chapter Two is long and relatively complex. Some basic material is appended and the reader is encouraged to refer to the relevant appendices as required.

Chapter Three, 'Voluntary Control Of Vasomotor Activity', reviews three major methods for controlling peripheral vasomotor (and hence temperature) activity. Chapter Three begins with a review and discussion of classical vasomotor conditioning. Operant training of hand temperature is reviewed and discussed followed by the related issue of cognitive vasomotor control. Integrated and combined studies which have examined the relationship and interaction of classical, operant, and cognitive temperature control are discussed next. The treatment package used in the present study is then discussed as a specific combination of classical conditioning, operant conditioning, and cognition. The chapter closes with a restatement of the purposes of the study and the listing of specific hypotheses to be tested.

Chapter Four, "Method", reviews the experimental procedures employed in the present study.

Chapter Five, "Results And Discussion", begins with the presentation of the combined data and a discussion of general effects relevant to the hypotheses directly under test. A case study analysis is then used to present

anomalous and demographic data as well as training information, incidental observations, and pertinent anecdotal material. A tentative component analysis and a number of theoretical and research issues are discussed next, in terms of the group and single subject data. The chapter closes with a brief summary of the results and conclusions.

1.2 Introduction

Man evolved in a restricted thermal environment, and his performance is optimal only within a very narrow temperature range. Progressively decreasing temperature below that range is accompanied by deterioration of organismic efficiency including such physical measures as: strength (Kay, 1949), agility (Kazantzis, 1967), manual dexterity (Kay, 1949), and tactile sensitivity (Mackworth, 1953). With continued exposure brain efficiency becomes progressively impaired (Poulton, 1970) leading to decreased vigilance (Poulton, Hitchings, & Brooke, 1965), and poor judgement (Poulton, 1970).

Fortunately, man has learned to minimize disruptive climatic effects by isolating himself from the cold with sophisticated micro-climates including highly insulative clothing. However, if he is to maintain the environmental contact necessary to his survival, man can not completely isolate his primary perceptual and effector systems. The hands and the face, thus, remain the least isolated and the

most vulnerable parts of the body. Very sophisticated efforts to preserve hand temperature through increased insulation have been made (Kitching, Bently, & Page, 1942). Such attempts inevitably obstruct movement and lead to decreased hand efficiency. For delicate or precise work, hand protection must be removed altogether.

The effect of cold on hand efficiency is clear. Kay (1949), one of the first to relate manual perfromance to hand skin temperature, obtained the results shown in Figure 1-1 with six subjects. He found fine manual dexterity, coarse manual dexterity, and hand strength to decline progressively as hand temperature decreased. Further, extended practice performing fine manipulations in the cold has been found to produce minimal reduction of cold induced impairments of dexterity (Clark & Jones, 1962).

Mackworth (1953, 1955) studied finger numbness in 35 men who had exposed the tip of an index finger to a cold wind and demonstrated that only gross tactile sensitivity occurs at skin temperatures below 15 degrees Celsius. As shown in Figure 1-2, he measured two point discrimination at the finger tip and found that the ability to say if the skin was in contact with one or two points deteriorated rapidly as the temperature declined. Although this progressive loss of sensitivity occurs in tactile sensitivity, pain sensitivity is unimpaired.

Wolf and Hardy (1941) investigated the pain produced by hand immersion in cold water. They described the sensation

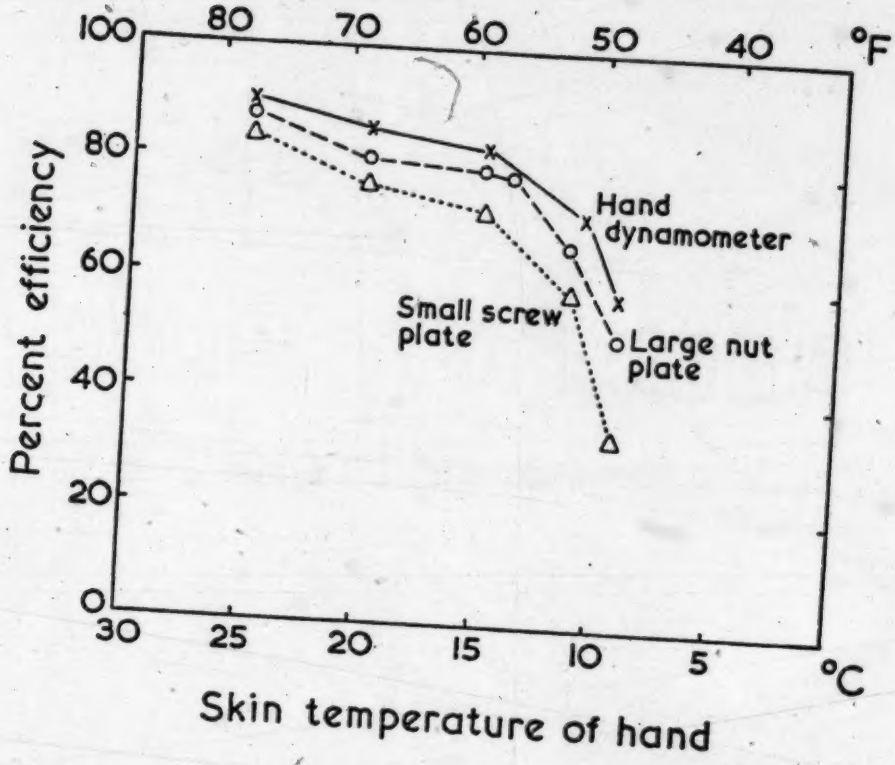


Figure 1-1

The decrement in manual performance which accompanies decreasing hand skin temperature. (The solid line represents hand strength; the broken line represents the number of 0.6 inch hexagonal nuts threaded onto screws; the dotted line shows the number of 0.2 inch screws screwed into a metal plate.) (From Kay, 1949)

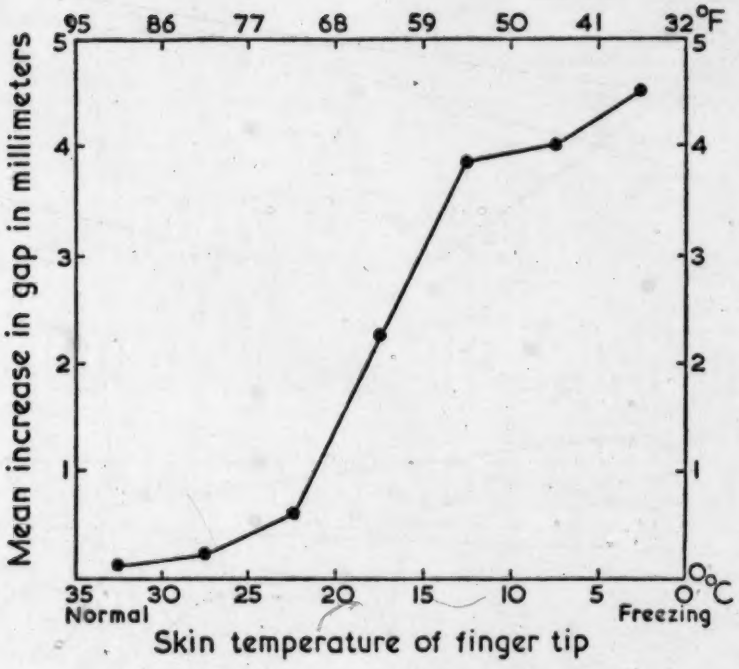


Figure 1-2

The increase in gap size on a 2 point discrimination task at decreasing skin temperature. (From Mackworth, 1955)

as a deep aching pain, the intensity of which was directly related to the water temperature. For untrained subjects ice water is frequently sufficiently painful to cause fainting or unwillingness to continue in the experimental situation (LeBlanc, 1975). The immersion of one finger is experienced as no less painful than the immersion of an entire hand (Wolf & Hardy, 1941). Repeated cold pain creates a general fear of the cold in many people so that in applied industrial and military settings the fear of cold pain alone frequently prevents workers from attempting to perform manual tasks which could be done in complete physical safety (Coffey, 1956).

In summary, cold hands are weaker, less dexterous, and less sensitive than warm hands. In very cold settings, hand function is sufficiently impaired that delicate or precise work becomes difficult or impossible. Further, many people experience cold pain as being so intense that they are unwilling even to attempt to perform tasks in the cold.

In cold surroundings extrinsic warming of the hands has been shown to yield improved manual efficiency and reduced pain even in conditions of extreme body stress. Lockhart (1966, 1968) for example, seated 12 men dressed only in cotton shorts and socks, in a room at 5 degrees Celsius for 20 minutes. Mean skin temperature of the men fell to 20 degrees. Six subjects then inserted their hands only into a heated box (32 degrees Celsius) and performed a series of manipulative tasks including stringing small blocks, packing

them into a box and tying standard knots with string. The other six performed the same tasks in boxes heated to 8 degrees. The warm hand group performed considerably better than the cold hand group.

Gaydos and Dusek (1958) and Gaydos (1958) obtained similar results on two conceptually similar studies. Gaydos and Dusek concluded that "Finger temperature seems to have been the primary determinant of manual performance decrement" (page 337). Gaydos was able to extend his findings even further:

> It was concluded that hand temperature is a vital factor in fine manipulation, but the body can be cooled to a degree which is distinctly uncomfortable without affecting manual performance if the surface temperature of the hands is maintained at normal levels

Numerous recent experiments (reviewed extensively below) have demcnstrated that intrinsic handwarming through voluntary vasodilation may be achieved in human subjects in warm ambient temperatures. Taub (1977) has demonstrated that such voluntary handwarming can be maintained concurrent with the performance of a cognitively complex task and while experiencing whole body cooling. To this writer, it seems reasonable to suggest that intrinsic hand warming, like extrinsic hand warming, should produce increased hand efficiency. The present study is an attempt to investigate that suggestion.

The rationale of the present study can be summed up in

three steps. First, within a cold environment, warm hands appear to function more efficiently than cold hands. Second, people can be taught to warm their hands voluntarily. Third, if this effect can be reliably produced in the cold and performed concurrently with complex tasks it appears likely that cold-induced impairment of hand function may be reduced without the use of gloves or other insulative devices.

2. MAN IN THE COLD

2.1 Overview

Men have used their hands in the cold for tens of thousands of years. In this time they have evolved the capacity for a range of complex physiological and behavioral mechanisms which can maximize hand protection against freezing as well as allow a reasonable level of cold hand efficiency. The present chapter reviews these various mechanisms and the conditions which must occur in order to activate them within individuals. From this context, the present study may be seen, partly, as a procedure to activate evolved cold-coping mechanisms without requiring constant and extended outdoor winter living.

Chapter two begins with a discussion of the behavioral and physiological mechanisms which permit organismic survival during cold exposure. Emphasis is placed jointly on increased insulation by decreased peripheral circulation and on shivering thermogenesis as the major protective mechanisms. The notion of organismic adaptation by increased thermal capacity is introduced along with a discussion of the reasons why few humans ever achieve more than the beginnings of this state.

Human adaptation is shown to consist primarily of reduced emotionality through central nervous system habituation, accompanied by a marked reduction or termination of shivering thermogenesis and cold pain. The

usual thermal cost of this adaptation is mild core hypothermia. Further, human adaptation is shown to be; slow and painful to develop, of small magnitude in the early stages, variable, and rapid to dissipate. Indian and Eskimo whole-body adaptation is shown to be qualitatively similar to white adaptation but with greater basal metabolic rate (BMR) and physical fitness as well as less body fat.

A discussion of the major organismic variables known to influence cold hand functioning includes; body size and shape, sub-cutaneous fat, physical fitness, sex, chemical and emotional vasoactive agents, diets, and diet supplements.

The phenomena of cold induced vasodilation (CIVD) and the "hunting reaction" are introduced and discussed as vascular occurrences in non-adapted hands. The roles of arteriovenous anastomoses (AVA) and other circulatory structures are discussed as the effectors underlying both phenomena.

Adapted Caucasian hands are shown tc be warmer than non-adapted hands as a result of less intense initial vasoconstriction accompanied by the earlier onset and increased reactivity of CIVD upon cold exposure. The result of adaptation is a reduction in pain and the cold pressor response as well as greater hand efficiency. Different aspects of hand-adaptation control are shown to occur both in the central nervous system and in local humoral, neural, and somatic tissues. The acquisition, nature, and

persistence of hand adaptation are discussed. Some small degree of Caucasian hand adaptation is found after as little as three weeks exposure although a much longer exposure appears necessary to get a strong and generalizeable effect. Even in fully adapted hands, the circulatory effects are found to undergo daily and seasonal variation. Little clear evidence is available on the persistence of the effect following extended periods of warm exposure. The thermal expense of hand adaptation is seen to be minimal (negligible to a physically fit person) with no deletereous effects to the organism.

The literature shows the adapted hand to be more efficient in the cold. In general, adapted hands are stronger, more sensitive, more dexterous, and less subject to pain than non-adapted hands. The even warmer Indian and Eskimo hands are seen to permit very fine movements even after extended, bare-hand, outdoor work. Although Indians and Eskimos lose more heat from the hands than whites this loss is homeostatically trivial given otherwise warm clothing.

2.2 General Aspects Of Cold Tolerance

Cold tolerance may be achieved both by decreasing the rate of organismic heat loss and by increasing overall heat production. The physiological reduction of heat loss is achieved in large part through control of the peripheral circulation (Burton & Edholm, 1955; LeBlanc, 1975). In

general as the ambient temperature decreases, a decreased volume of warm blood is circulated from the body core through the periphery. Consequently, the peripheral tissues cool rapidly and the result is a steeper heat gradient from the body core to the skin (Burton & Edholm, 1955). The new cooler periphery supplies less heat to the environment and thus retains more central heat. In effect, the cooled peripheral tissue may be conceptualized as a layer of insulation between the warm body core and the cold environment.

The reduction of peripheral blood flow in response to cold has been widely investigated and found to result primarily from decreased circulatory capacity although the increased blood viscosity which results from blood cooling also has some effect (Barcroft & Edholm, 1943; LeBlanc, 1975). In cool temperatures, the decreased heat loss due to decreased peripheral blood flow (i.e., the conversion of heat dispersing tissue to insulation) is often sufficient to maintain core temperature without the onset of additional physiological responses.

In colder ambient temperatures heat preservation by cutaneous vasoconstriction may not be sufficient to maintain core temperature so that extra heat must be generated and supplied. From the physiological perspective this may be done in three ways. First, in the short term, the metabolic state may be changed by increasing muscular output (cold resistance). Second, in the longer term, the basal metabolic

rate may be increased by repeated or continuous exposure to cold (i.e.,increased cold toleration capacity or adaptation). Finally, metabolic traits may be changed genetically across generations of cold exposure. Each of these rubrics is discussed in turn below.

Shivering is the normal, short term, physiological mechanism for increasing heat production. It, like decreased peripheral blood flow is a mechanism of immediate cold resistance but does nothing to increase the capacity of the organism to endure cold. Shivering onset is marked by suddenly increased muscular tonus which supplies a small amount of heat. If this is not sufficient to return the system to a thermal steady state, shivering thermogenesis begins. Shivering is more or less vigorous, depending on organismic heat needs (Burton & Edholm, 1955). At its maximum, shivering can increase the metabolic rate by up to seven times the basal level for short periods (Burton & Edholm, 1955).

If exposure to severe cold is repeated often enough, or is maintained over a sufficiently extended time period, the organism's non-muscular heat production capacity begins to increase, enabling a gradual, progressive reduction in shivering (LeBlanc, 1975).

Nonshivering thermogenesis signifies organismic adaptation to cold stress through increased metabolism and hence more available heat to resist the cold. In effect, successful cold adaptation indicates that the organism has

extended the limits of his resistance to the cold. LeBlanc (1975) illustrates this point by comparing the temperature of irreversable hypothermia onset in non-adapted rats (-18*C) with adapted rats, which have lived for several weeks at temperatures slightly above freezing, (-37*C).

A plethora of physiological studies of cold adaptation in rats and other animals has demonstrated that adaptation may be induced by: continuous exposure to moderate cold (Depocas, Hart, & Heroux, 1959; Depocas, 1960; Hart, & Jansky, 1963; Jansky, 1966)); and to some extent by rigid dietary control (Heroux & Petrovic, 1969), dietary supplementation (Desmarais & LeBlanc, 1952; Dugal & Therien, 1947; Dugal, 1952; Therien, LeBlanc, Heroux, & Dougal, 1949), and by synthetic preconditioning with a wide range of endocrineological agents (LeBlanc & Villemaire, 1970 ; LeBlanc, 1975). Unfortunately, it is not at all certain that the results of specific animal findings are applicable, or even parallel, to human functioning so, except for a few specific studies (discussed below), the body of animal literature is not reviewed more extensively here.

Human adaptation parallel to the animal studies is rare because, with few exceptions (reviewed below) modern man is neither inclined nor likely to expose his whole body sufficiently to achieve even minimal levels of nonshivering thermogenesis. Instead, modern man occasionally develops a special type of adaptation following exposure of the extremities alone. This unique type of adaptation is only

partly related to nonshivering thermogenetic adaptation and is more appropriately considered below under the rubric of 'The Exposed Hand In Cold Temperatures'.

2.3 General Aspects Of Human Cold Adaptation

2.3.1 Contemporary Man

2.3.1.1 Adaptation By Habituation

Contemporary man is seldom exposed naked to cold for long enough to produce nonshivering thermogenesis. There is considerable evidence, however, that a unique form of adaptation (called "Habituation Adaptation") may occur in adequately clothed men who are exposed intermittently to severe cold and/or for long periods of time to moderate cold. Habituation adaptation is similar to animal adaptation in that there is a marked reduction or complete cessation of shivering over a period of months (LeBlanc, 1956; Davis & Johnston, 1961) or years (Budd, 1962, 1964; Budd & Warhaft, 1966). Unlike other animals humans do not usually replace muscle-generated heat (shivering) with non-shivering thermogenesis. In most cases the price they pay is mild core hypothermia (LeBlanc, 1956; Davis & Johnston, 1961), although in some cases core temperature may be maintained but at the cost of even further depression of peripheral circulation and temperature (Budd, 1962).

LeBlanc (1975) drew upon a diverse range of evidence to propose a mechanism for habituation adaptation. Cold is a painful and occasionally frightening stressor which may pose

a real danger to the uninitiated and the untrained. It has been demonstrated that cold, like a number of other stressors, may selectively activate adrenaline and noradrenaline secretion in humans (Von Euler, 1954; LeBlanc, 1975). These substances, acting either alone, or in company with central trigger mechanisms then stimulate and/or enhance shivering. When a clearly defined stressor is repeated without organismic damage or it becomes evident that no real danger is involved, rapid central nervous system habituation to the stressor occurs. Habituation is accompanied by reduced output from the adrenal medulla (Frankhauser, Sterky, & Jaerpe, 1962). On the other hand, when exposure to the stressor causes organismic damage or there is evidence of continuing real danger (e.g., in parachute jumping) this type of habituation does not occur (von Euler, 1967). Thus, LeBlanc (1975) argues, repeated partial exposure to severe cold (a clearly defined stressor) without actual damage results in central nervous system habituation, eliminates the emotional aspect of the stress, and in the process reduces or eliminates shivering without enhancing the production of additional metabolic heat production.

2.3.1.2 Characteristics Of Habituation Adaptation

Habituation adaptation is slow to develop, inversely related to air temperature, and appears to fluctuate even during periods of relatively stable cold exposure (Budd,

1974; Tikhomirov, 1974). Tikhomirov (1974) reviewed the main trends of all prior Soviet medical investigations in Antarctica and identified four phases of human acclimatization. The phase of "initial adaptation" lasts two to four weeks and is marked by strong subjective sensation with considerable reactivity and change across all functional indices of stress. The phase of "major acclimatization" extends over the succeeding four to six months, is marked by a gradual reduction of all functional stress indices, and is accompanied by better health and in many cases, better fitness. During phase three, "relative acclimation", all stress indices return to their initial levels and remain more or less stable over some indeterminate period of time.

Phase three appears to correspond to the acclimatization investigated by LeBlanc (1956), Davis and Johnston (1961), Budd (1962, 1964) and Budd and Warhaft (1966) as discussed above. Tikhomirov's fourth phase "full acclimatization" involves a return to organismic equilibrium with increased capacity for heat production. The onset of full acclimatization occurs after three to ten years of continuous severe cold exposure but, even then, occurs only at rest, not at work.

There is, as yet, no evidence regarding the persistence of full acclimatization in Caucasians who have returned to warm settings although Budd (1962) and Budd and Warhaft (1966) re-exposed all their subjects (who had spent 73 weeks

in Antarctica) approximately six weeks after their return to summertime Australia and found only a very small degree of acclimatization remaining. Further, all subjects were even less able to maintain rectal temperature than before their initial encounters with the cold.

2.3.1.3 Habituation Adaptation And The Present Study

The relevence of habituation adaptation to the present study is most clear when one restates the above discussion in terms of work efficiency. Increasing adaptation signifies a progressive reduction in stress and an increasing ability to function in the cold. Moderate work efficiency is not reached until after months of exposure and peak efficiency may not be reached at all without years of unbroken cold immersion. Once developed, cold efficiency is lost simply by exposure to warm summer weather.

Recall that habituation adaptation results primarily from hand and face expcsure. If the present study is successful, the hands should behave much like the hands of habitually adapted persons except that this artificial adaptation would be rapidly taught and relatively permanent without the need for an extended habituation period. (This topic is discussed at much greater length below.)

2.3.2 Primitive Man

For the present review, the primary interest in primitive groups centers on their special cold-adaptive hand

mechanisms. It must be remembered, however, that specific mechanisms are learned and/or evolved within organismic, cultural, and environmental contexts. Consequently, it is highly inappropriate simply to pluck out and discuss a specific evolved mechanism without some understanding of its developmental context. The present review of primitive people is very brief and includes only information which is believed to be relevent to a later discussion of specific adaptive hand mechanisms.

2.3.2.1 General Classification Of Primitives

Hammel (1960) suggests that most reported studies of man in the cold (excluding Eskimos and Northern Indians) can be grouped into one of three standard patterns. The "non-adapted Caucasian" pattern starts an overnight cold exposure with a near basal metabolic rate that increases rapidly through shivering as body temperature falls. The "Australian Aborigine pattern" begins with a normal basal metabolic rate that progressively decreases while both core and surface temperatures fall to lower levels than in control group Caucasians. This pattern indicates the development of a clear physical tolerance to hypothermia. The "Alacaluf Indian pattern" begins with a basal metabolic rate 60% higher than the white man. Alacaluf metabolic rates and core temperatures decline slightly from their starting points over the course of the exposure.

Of Hammel's three patterns, only the un-adapted

Caucasian shows an increase in metabolism through shivering. In other words, most naked or semi-naked primitives appear to control both metabolism and temperature in the same qualitative fashion as habituation-adapted Caucasians. Initial metabolic rates and magnitudes, of course, vary widely between groups.

2.3.2.2 Northern Indians And Eskimos

Within Hammel's classification and in terms of whole body responses, Northern Indians and Eskimos behave like un-adapted Caucasians. This is probably because, like un-adapted Caucasians, they have developed such efficient micro-climates that they seldom experience whole body contact with the cold (Hammel, 1960). In terms of extremity exposure, however, their response is very unlike that of the white man.

In the present study, a later assumption is based upon Indian and Eskimo extremity adaptations so that some further information about the overall adaptation of these races is given here.

The Eskimo's basal metabolic rate (BMR) has been reported to exceed the white man's by 13% (Hygaard, 1941) to 40% (Rennie, 1963). Basal metabolic rates of the various Northern Athapascan Indian tribes range from equal to the Caucasians (Meehan, 1955) to 14% higher (Irving, Anderson, Bolasad, Elsner, Hildes, Loyning, Nelms, Peyton, & Whaley, 1960). Very high consumption of protein has been suggested

as the reason for the high BMR in Eskimos (Krough & Krough, 1913; Milan, 1962). During whole body cold exposure Eskimos shiver as powerfully as the un-adapted Caucasian and exhibit a parallel rise in metabolism (Adams & Covino, 1958).

The difference between resting Caucasian and Eskimo BMR is also known to be maintained during shivering (Adams & Covino, 1958) and exercise (Rodahl in Milan, 1962). Shivering onset occurs at an average skin temperature of 30*C in both Eskimos and Non-acclimatized Caucasians (Rennie, 1963). After prolonged cold exposure both Northern Indians (Meehan, 1955) and Eskimos (Milan, 1962) shiver more than un-adapted Caucasians. Eskimos (Covino, 1960) and Indians (Irving et al., 1960) are lean peoples with a body fat content less than physically fit Caucasians. As a result of low fat levels, heat loss during cold water submersion is greater in Eskimos than in Caucasians (Covino, 1960). Both Eskimos and Northern Indians are consistently reported as physically fit.

In summary, Indians and Eskimos respond to whole body cold in the same qualitative manner as un-adapted Caucasians although quantitatively, they are slightly more sensitive and vulnerable. For the remainder of this study Indians and Eskimos are considered equivalent to un-adapted Caucasians in terms of whole body response to cold. This equivalence becomes significant in a later section (Primitive Hands) when it is demonstrated that Northern Natives can maintain apparent thermal stress without impairment of

thermoregulatory mechanisms such as shivering. It is argued below (with additional evidence) that if Eskimos can tolerate the heat loss due to maintaining warm hands then the fit Caucasian can do likewise.

2.4 Organismic Influences On Hand Effects

The functioning hand should not be logically isolated from the body to which it is attached. The prime movers of the fingers, hand, and wrist are located outside the hand, in the forearm. Most sensory information originating in the hand is subsequently registered, selected, modified and processed in some more proximal neural center. Much, perhaps most, smooth and striated muscle action in the hand is controlled by nervous signals originating in more proximal nervous centers. Humoral influences, which represent overall body states, are transmitted to the hand primarily through the circulatory system. The major non-pathological, individual variables discussed in the present section are those non-racial variables which act indirectly on hand circulation through their effect on organismic capacity to produce and control heat.

2.4.1 Body Size And Shape

Other things being equal, body size and shape affect the rate of organismic heat loss (LeBlanc, 1975). Relative heat loss is greater for small people because they have a larger surface area per unit of body weight (heat capacity).

Similarly, long arms and legs or tall slim bodies expose more surface area per unit of volume and thus lose more heat than short thick members and bodies.

2.4.2 Subcutaneous Fat

Subcutaneous fat is minimally vascularized and much less thermally conductive than other body tissues (Burton & Edholm, 1955). Other things being equal, the insulating properties of a thick subcutaneous fat layer allow a greater decrease in skin temperature accompanied by greater retention of core heat than a thin subcutaneous fat layer. LeBlanc (1954, 1975) suggests that thick fat is of little importance at 70 *F but becomes increasingly important as temperature declines. At 50 *F or lower, it may acccunt for a large part of individual variation in cold tolerance. LeBlanc (1975) based his conclusion upon his 1954 observations that lean, cold-exposed people shiver more vigorously, more quickly, and at higher skin temperatures than fatter controls.

2.4.3 Physical Fitness

Physical fitness may be a limiting factcr in organismic cold tolerance particularly when environmental demands are extreme or sustained (LeBlanc, 1975). The more fit a human being is , the more likely he is to have large aerobic (and hence heat) capacity as well as a large and vascular musculature. These characteristics permit a greater

intensity and duration of physical efforts (including shivering) which can produce heat after other defenses are exhausted.

2.4.4 Chemical Agents

Many agents are known to induce vasodilation or vasoconstriction of the hand, sometimes with no effect on other parts of the body. Marble (1960) has reviewed many of these agents and in general his conclusions are as follows. Emotions are powerful vasomotor agents. Pain, anger, and fear elicit intense, rapid vasoconstriction, but the constrictor action of anger is released when it gives way to physical action. Reported happiness, on the other hand inhibits sympathetic discharge and allows vasodilation. Common whole body vasoconstrictors listed by Marble include: cold, mental work (problem solving), hyperventilation, and skin trauma. The smoke from one cigarette may cause a sudden finger temperature decrease of between 5.3 and 15.5 F* with a profound reduction or complete cessation of nailbed capillary blood flow. Common whole body vasodilators include: any external heat source, exercise, high protein food, and drugs containing stilbestrol, histamine, and acetylcholine. The effect of heat is relatively greater on the hands than on other body parts. A hot bath, for example, may induce a 50-fold hand circulation increase.

2.4.5 Diets And Diet Supplements

With few exceptions, diets and diet supplements have little effect on human cold habituation and adaptation (Burton & Edholm, 1955). Glickman, Keeton, Mitchell & Fahnestock, (1946) investigated the effects of thiamine, riboflaven, niacin, and ascorbic acid and found no effect on heat-related or phycho-motor performances. Subsequent studies of massive vitamin C intake have demonstrated that vitamin C may reduce cold pain and induce higher overall skin temperature (LeBlanc, Stewart, Marier & Whillians, 1954). LeBlanc (1975) reports that on the basis of this study and others by Linus Pauling, U.S. and Canadian military personnel are routinely supplied with 500 mg of vitamin C per day while engaged in northern activities.

The well-known craving of fat which develops on prolonged Arctic (Steffanson, 1944), and Antarctic (Frazier, 1945) expeditions does not appear to enhance cold tolerance unless high fat content meals are eaten at two hour intervals or oftener (Mitchell, Glickman, Lambert, Keeton & Fahnestock, 1946).

2.5 The Exposed Hand In Cold Temperatures

Hand function in the cold has been extensively investigated by many disciplines and from many aspects. Environmental and human engineers have attempted to construct better heat sources and more efficient hand insulation (Kitching, Bently & Page, 1942). Medical studies

have experimentally investigated the nature and treatment of cold injuries (c.f., Cold Injury). Pharmacologicical studies have reported chemical influences on hand cold tolerance and adaptation (LeBlanc et al., 1954). Physiological studies have examined numerous anatomical structures, physiological mechanisms and complex, organismic temperature-control systems as they apply to the hand. Human geographers and anthropologists have studied the hand from many perspectives including; racial and geographical adaptation, and behavioral coping mechanisms.

The material discussed below is not proportionally representative of the vast body of existing cold hand literature. Instead, the selected material reflects the fact that the independent variables in the present study are drawn directly from educational and behavicral psychology. As such, the primary concern is with observable, extra-dermal hand effects which occur as the result of environmental manipulation. It is not always possible, nor even desirable (in this study) to speculate on the internal workings which bring about that change.

The relevence of some physiological studies is difficult to ascertain. Certainly some knowledge of sub-dermal events is necessary before the present study can be undertaken. Knowledge of the function and anatomical placement of cold-stimulated, dermal, vasodilative thermo-effectors can clearly assist in electrode placement and representative material is discussed. The benefits of

considering other cold responsive dermal micro-circulation controls and effects are less clear, and they receive proportionally less coverage. (See Appendices B and C for more extensive discussion.) Major arterial and venous circulation is least likely to undergo change in this study and a discussicn cf the vessels is appended (Appendix A). The workings of vessicular smooth muscle: of the ten or twelve interactive levels of neurological mechanisms which control that muscle (Hensel, 1973; Bard, 1960); and of the three or four levels of interactive humoral function (Itoh, 1974) which may control circulation either directly (LeBlanc & Rosenberg, 1957), or in concert with the neural mehanisms (LeBlanc, 1960) are not discussed. In general, sub-dermally oriented studies have been de-emphasized unless they are of clear or marginal interest.

Engineering, pharmacological, and medical studies have been reviewed but are not discussed here. Inter-racial studies of all kinds have been reviewed, but only far northern natives falling under the rubric of "un-adapted Caucasian patterns" (excluding the Finns, Lapps, and Skolts) are extensively discussed.)

2.5.1 Non-Adapted Hands

Sir Tom Lewis (1930), the first man to study cold effects on hand blood flow, measured the skin temperature of Caucasian fingers immersed in stirred ice water. He found that skin temperature dropped rapidly almost to 0 *C but

rose again by 5 or 6 *C within 12 to 15 minutes. This sudden temperature rise subsequently became known as Cold Induced Vaso-Dilation (CIVD). With continued immersion, finger temperature continued to fluctuate between 0 *C and 5 *C, a phenomenon which Lewis (1930) termed the "hunting reaction". Microscopic studies of rabbit ears by Grant and Bland (1931) showed that such temperature increases were due, in large part to the sudden opening of tiny, direct, circulatory shunts between the arterial and venous systems called arteriovenous anastomoses (AVA). This finding was confirmed by Fox and Wyatt (1962) who demonstrated the occurrence of CIVD in all areas where AVA are known to exist. (See Appendix B for a more extensive discussion of the structure, function, number, and control of the AVA.)

Human AVA are located in peripheral skin areas usually around and superficial to the sweat gland tubules (Nelms, 1963). Clara (1939 in Burton & Edholm, 1955) estimated an approximate density of 500 AVA/sq. cm in the nail beds, 236/sq. cm in the finger tips, and 93/sq. cm in the skin of the proximal phalanx. Nelms (1963) suggested an approximate concentration of 200 AVA/sq. cm in the sole and 100/sq. cm in the volar surfaces of the palm and fingers. In rabbit ears, the number of AVA at any given site may increase following repeated cold exposure, trauma, mild infection, and artifically sustained increases in blood flow (Nelms, 1963).

Arteriovenous anastomoses dilate fully during CIVD.

When one considers that the dilation of a single AVA from 10 to 60 microns may increase blood flow by 1000 times (Nelms, 1963) it becomes apparent that AVA play a very significant role in blood (heat) flow in the hand. In addition to the direct surface heating effect, increased peripheral circulation implies an increased rate of arterial and venous flow and hence less time for arterial blood pre-cooling. Higher arterial and venous blood temperatures may thus supply additional heat to tissues surrounding the major vessels as a direct result of increased AVA flow.

In general, CIVD is not a highly stable phenomenon. Onset temperature, magnitude, and rate of recurrent cycling are all known to vary across individuals (Milan, 1962), time of day (Aschoff & Heise, 1972), season (Budd, 1964), and individual hand exposure history (LeBlanc, 1975). For a discussion of AVA control mechanisms see Appendix C.

In addition to AVA many other circulatory hand structures are known to contribute to CIVD as well as more general aspects of hand temperature control. Nelms (1963) in fact, has suggested that the major function of hand skin circulation is to control blood pressure and regulate temperature rather than to nourish the skin. Nelms describes hand skin blood vessel anatomy as follows:

> The circulation passes through plexuses of interconnecting vessels at different levels in the dermis. An arteriolar plexus in the deep dermis sends branches to the more superficial arteriolar plexus from which metarterioles pass to the dermal papillae, becoming, by way of precapillary sphincters, the capillary loops of the papillae. The venous outflow passes to a subpapillary venular

> plexus from which the tributaries of candalabrum veins lead to the muscular veins of the deeper dermis. All these vessels except the actual capillary loops and the smallest veins have smooth muscle in their walls. (page 935)

All or any of these muscled and innervated vessels may contract in various patterns and combinations upon cold contact to reduce skin blood flow directly, and overall hand blood flow indirectly.

The vessels described above may also play some part in CIVD, although neither the relative strength nor the overall proportion of vessels which participate in the effect has been determined. It is generally agreed that the AVA, rather than the above microcirculation vessels play the major role both in CIVD and Lewis' (1930) hunting reaction. Cold induced vasodilation, in turn, is only one of the many hand responses which may occur following cold exposure. In summary, the effect of cold upon non-adapted hands has now been considered from several perspectives. One should recall the clear decreases in manual dexterity, hand strength, and tactile sensitivity, as well as the pain effects which follow cold exposure. Dermal circulation effects have been shown to include an initial decrease in blood flow, followed by CIVD, and the hunting reaction. These circulation effects may be regarded as organismic attempts to preserve initial loss of body heat, followed by effective prevention of tissue damage. The hunting reaction, in turn, represents a cyclical balance between these two opposed forces.

Sufficiently extended and/or repeated cold exposure brings about hand adaptations which consist partly of alterations in the normal hand circulatory patterns discussed above and partly of whole body modifications. The discussion of hand adaptation, which follows, begins with a consideration of circulatory modifications.

2.5.2 Cold-Adapted Caucasian Hands

Caucasian hand adaptation has been widely studied. There is universal agreement that adapted hands are warmer, less painful, less subject to frostbite, and more efficient in the cold than unadapted hands. There is less agreement on the locus of control, acquisition rate, and persistence of hand adaptation. Some measurements of the magnitude of heat loss increase due to adaptation have been made. Each of these consideration is discussed below.

2.5.2.1 Temperature Effects

There is universal agreement that the circulation effects of hand adaptation include a less intense initial vasoconstriction accompanied by the earlier onset and increased reactivity of CIVD upon cold exposure. That is, adapted hands are warmer in the cold than unadapted hands.

In a series of experiments LeBlanc, Hildes, and Heroux (1960), LeBlanc (1962), and LeBlanc, Pouliot, and Rheaume (1964) compared the hand temperatures of cold-adapted Gaspe Penninsula fishermen with appropriate control groups. In

every ice-water immersion comparison the fishermen exhibited higher hand temperatures. The difference was even more pronounced in cold air comparisons (LeBlanc, 1975).

Similar attenuated hand temperature decrease during cold water immersion has also been demonstrated in; Japanese fish factory workers (Itoh, 1974), fish filleters (Nelms & Soper, 1962), and in Norweigan fishermen by Krog, Folkow, Fox, and Andersen (1960). In every case where it was checked, cold termination was also followed by more rapid hand rewarming in the adapted subjects than in the controls (Itoh, 1974).

2.5.2.2 Pain Effects

Hand adaptation eliminates or drastically reduces cold induced pain. In the LeBlanc et al. Gaspe studies the fishermen were reported to have maintained their usual jolly behavior, complete with joking and laughing, during hand immersion. Controls were grim, reported the usual severe pain and several of them fainted during hand immersion. Blood pressure and heart rate increases were far lower in the fishermen than in the contols. Similar attenuated pain responses were found in all the fisherman and fish worker studies described above as well as on all Arctic and Antarctic expeditions (Rogers, 1974).

2.5.2.3 Locus Of Control: Behavioural Considerations

Of significance is the fact that hand pain adaptation

and hand temperature adaptation are not achieved by the same mechanisms (see below). Indeed, the experimental separation of hand pain adaptation from hand temperature adaptation within subjects has helped considerably in understanding some of the control mechanisms underlying hand (and to some extent whole-body) adaptation. This experimental separation is used below as an introduction to the discussion of hand adaptation mechanisms.

Prior to 1963 the local nature of hand adaptation lead most workers to attribute the effect, either implicitly or explicitly, to local vascular adaptation. However, Eagan (1963) compared the temperature and pain responses caused by the cold immersion of one untrained middle finger with the responses of the trained (810 ten minute ice water immersions) contralateral digit in six subjects. Temperature responses of both fingers were the same, but the untrained immersions produced severe pain while the adapted immersions did not. Eagan's demonstration of finger temperature adaptation without prior direct exposure provided convincing evidence of a central vasodilative control mechanism.

Glasser and Whittow (1957) had previously demonstrated a progressive decline in blood pressure and heart rate after 54 single hand immersions. Subsequent immersion of the opposite hand, however, produced the characteristic un-adapted cold pressor response. This finding was consistent with the Eagan (1963) study when one considers that the cold pressor response most likely occurs as a

result of the cold induced pain. Glasser, Hall, and Whittow (1959) provided further evidence of the central nature of hand pain adaptation when they overcame the effects of habituation and reinstated the cold pressor response by administering chlorpromazine, a central nervous system active agent which is known to abolish habituation to other stimuli. Although these behavioral findings appear to suggest that adaptation is exclusively central, substantial physiological evidence to the contrary has been obtained.

2.5.2.4 Locus Of Control: Physiological Considerations

Heroux (1957, 1959), LeBlanc (1959, 1963), and LeBlanc and Rosenberg (1957) have studied peripheral tissue adaptation per se and have found not only that local tissue and circulatien changes occur during adaptation but that these changes may have central effects. In general, local tissue adaptation is accompanied by increases in the number of skin capilaries, in the number of layers of the stratum corneum, and most important, in the number of hand skin mast cells (LeBlanc & Rosenberg, 1967; LeBlanc, Heroux & Hildes, 1960). Mast cells are major body producers of histamine and heparine (Riley, 1959), both of which, it may be recalled, are powerful systemic vasodilative agents. It is the cold-generated mast-cell vasodilators which appear to have nct only local, but central effects. The effect of local humoral secretions on central processes has been most extensively studied in animals.

In rats, for example, the genesis of new mast cells is most rapid during the first two months of cold exposure and then tapers off after approximately four months. Urinary histamine concentration shows a parallel marked increase during the first two months of exposure and then gradually tapers off, reaching pre-exposure levels in approximately 12 months (LeBlanc, 1961, 1963). LeBlanc (1963) reviewed this and other pharmacological evidence and suggested that in humans, excess systemic histamine (generated by increased hand mast cells) may assist in sensitizing cardiovascular and metabolic processes and thus assist in systemic adaptation.

Depocas (1960), Hseih and Carlson (1957) and LeBlanc (1961) have advanced a nearly parallel argument for the effects of excess noradrenaline which may originate in the noradrenergic nerve endings of the hand skin following repeated cold exposure (LeBlanc & Nadeau, 1961).

Any one of the above central and peripheral adaptive mechanisms is capable of producing some portion of the decreased intensity of vasoconstriction that is characteristic of hand adaptation. More likely, they all participate in some, as yet unknown, combination. To some extent, these mechanisms may also participate in the adaptive early onset and increased reactivity of CIVD although this point is less clear. (See Appendix C for a discussion of the control mechanisms underlying CIVD.)

2.5.2.5 Locus Of Control: Semantic Considerations

A separate central neural mechanism(s) based on habituation appears to control cold pain responsivity (Keatinge, 1963; LeBlanc, 1975). As we have seen, this mechanism is anatomically highly specific. It may also be tied to cognition through specific semantic classes and/or behavioural tasks. The best evidence for this possibility has been provided by LeBlanc and Potvin (1966). They measured the blood pressure responses of a group of students during 2.5 minute mental arithmetic tests and during 2.5 minute hand immersions in 4*C water. The students then trained by combining hand immersion with mental arithmetic for 2.5 minutes, twice a day for 19 days. As expected, blood pressure decreased over exposures while scores on the arithmetic quizzes increased from approximately 50% to 100%. After 19 days the students were again exposed separately to each stressor. Their final blood pressure responses had not changed as a result of training.

The students, in this case, may have learned exactly what they were taught and thus were unable to maintain their pain habituation when the nature of the task changed. An alternate, more plausable, explanation is that the 38 2.5 minute immersions was far too few to have produced more than the beginnings of adaptation and thus the response was far too weak to transfer to a new stimulus context.

2.5.2.6 Performance Effects

The effect of physiological hand adaptation upon Caucasian cold performance has been investigated in laboratory and field settings although most reports are anecdotal. In general, warm and relatively comfortable adapted hands are more efficient than cold, painful, unadapted hands.

Mackworth (1953, 1955) provided quantitative evidence on the efficiency of hand adaptation. He exposed one finger of each of 35 volunteers to cold air (-25 to -30*C) for three minutes and demonstrated a clear, rapid decrease in ability to make tactile discriminations (two point limen test). Mackworth's 30 experimental subjects had lived in the cold environment of Fort Churchill for one to two years. Half of them spent most of their days indoors (indoor men). The other half (outdoor men) spent at least four hours per day outside. As shown in Figure 2-1 the indoor men showed a much greater decrement in sensitivity than the outdoor men. Mackworth (1955) found, however, that the acclimatization effect dissappeared with more prolonged, or more severe exposures.

In a second set of experiments Mackworth (1955) exposed 14 non-adapted well dressed (no gloves) British sailors in a -15*C cold chamber for two hours a day, five days a week for five weeks during the winter. After two hours of quiet sitting the exposed finger was inserted into a six miles per hour, -15*C wind for one minute. Figure 2-2 shows that cold

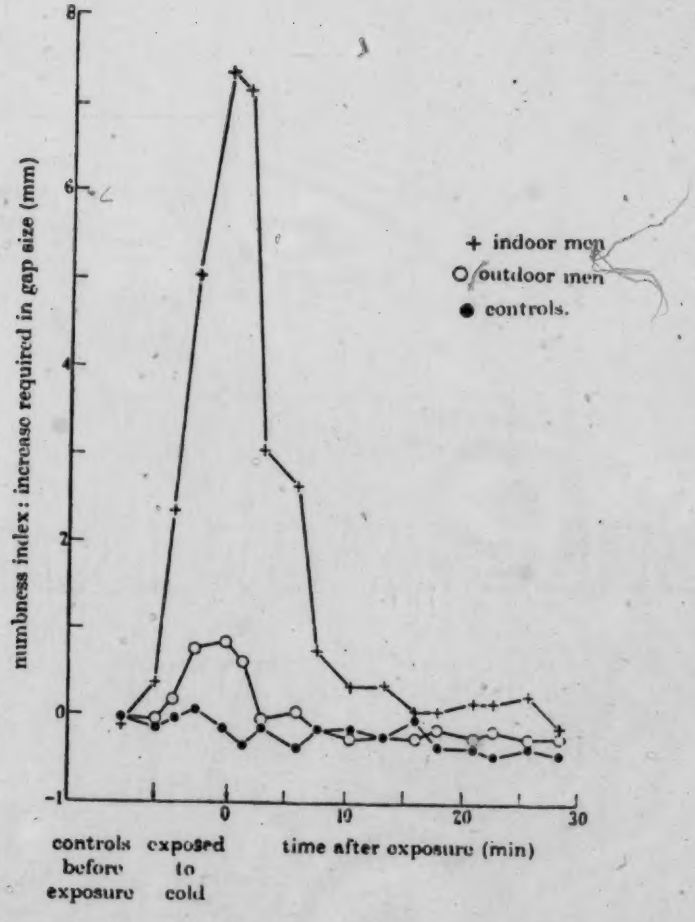


Figure 2-1

Comparison of the degree of numbness (ordinate) in fingers exposed to cold air, in outdoor and indoor workers and non-exposed controls, at Fort Churchill. (From Mackworth, 1955)

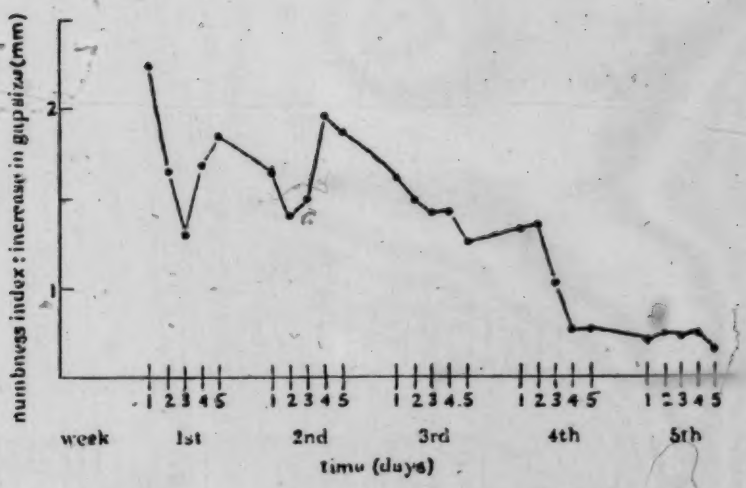


Figure 2-2

Day-by-day trends in V-test numbness index during cold acclimatization exposure in the winter months. (from Mackworth, 1955)

induced impairment of tactile sensitivity declined steadily over four weeks and then remained stable. Mackworth (1955) was unable to replicate these results during the next British summer when the average outdoor temperature was 21*C.

Burton and Edholm (1955) drew two conclusions from Mackworth's series of experiments. First, local (finger) acclimatization to cold can be developed in man. Second, exposure to heat can prevent acclimatization.

Rogers (1974) observed the hands of polar expedition members before and after the polar crossings of 1957-1958. All expedition members were well clothed, physically fit and very experienced in the cold. Following the 16 week polar crossing (mean temperature was -30*C) it was common to see men working outdoors for up to half an hour without damage or apparent discomfort when the temperature climbed to -20*C. New arrivals at Scott base experienced difficulty working for half hour periods at -20*C even though they wore both gloves and mitts.

These studies should not be interpreted as showing that hand adaptation negates cold impairment. Indeed, Clark and Jones (1962) have shown that even extended practice in the cold only partly compensates for cold induced disability. This writer had been unable to locate any evidence at all that cold adapted hands are capable of perfcrming fine or precise manual tasks in the cold.

2.5.2.7 Stability Effects

Relatively little attention has been directed to the experimental exploration of such hand adaptation variables as; acquisition rate, effect magnitude, seasonal variation, response persistence, and increased or decreased heat loss due to adaptation. The lack of literature in this area represents primarily a general reluctance to compare quantitative physiological measures obtained from different field studies, particularly when the differences are small. The difficulties lie with the differences found both in instrumentation and in the nature of the diverse field populations. Hammel (1960) has clearly expressed the reason for discouraging such comparisons:

> It is possible that all differences would vanish should it be possible to maintain all groups under exactly the same conditions as to kind of food ingested, degree of cold exposure prior to testing, physical fitness, physical and mental health, etc., and after this study them with exactly the same tests. Only in the laboratory would one wish to attempt to meet these exacting conditions. (page33)

The problem is compounded when one considers that even in most of the classic laboratory studies hand exposure was not continued until the indices of habituation stabilized. Although such studies may have provided clear qualitative and directional information they have not since lent themselves well to quantitative comparisons. In this spirit, most of the information discussed in the remainder of the section on Cold Adapted Caucasian Hands should be considered

tc represent loose indicators of probable (possible) boundaries.

2.5.2.8 Stability Of Acquisition

In the laboratory, evidence of hand adaptation by immersion had been reported after as few as 38 2.5 minute immersions over 19 days (LeBlanc & Pctvin, 1966) to as many as 810, 10 minute immersions over 125 days (Eagan, 1963). Dependent measures of hand adaptation to prolonged cold air exposure have generally been made following cold chamber (-10*C to -25*C) exposures of one to three hours per day for five or six hours per day for four to eight weeks.

In the field, subjects have been considered as hand adapted following 16 weeks (Rogers, 1974), to 10 years (Tickhomirov, 1974), or even lifetimes (Itoh, 1974) of unbroken cold climate residence. In essence, different studies may report different kinds and levels of hand adaptation under the same general title of 'adapted'. Never-the-less, some amount is known about the seasonal variation and persistence of hand adaptation.

2.5.2.9 Seasonal-temporal Stability

Itoh (1974) reviewed the literature dealing with the metabolic changes that occur in response to seasonal and diurnal changes of temperature, light, and nutrition. In general, these factors include; serum water volumes, blood volume, urine volumes, many types of electrolyte

concentrations, six endocrineological agents, and plasma lipid concentration. Each of these factors is known to affect cold performance when experimentally manipulated. Further, each of these is known to vary seasonally.

Elkington (1968) studied finger blood flow in acclimatized men in the Antarctic and found a pronounced seasonal blood flow variation. Both the overall finger blood flow (cold immersed and non-immersed) and the overall magnitude of CIVD were lesser in the colder months. Elkington attributed this seasonal effect to the interaction of hand adaptation with whole body adaptive mechanisms. Unfortunately, a non-adapted population was not available to Elkington so that he could not control for seasonal metabolic fluctuations.

LeBlanc (1966) found seasonal variation in the cold pressor response of the Gaspe fishermen along with parallel changes in his control subjects. Itoh (1974) confirmed LeBlanc's finding when he found greater blood pressure changes during summertime than wintertime in eight subjects. These studies suggest a clear decrement in cold tolerance over the warmer summer months for both adapted and un-adapted hands although it is not clear if adaptation per se. is affected.

Many studies have found heat loss from the hand to undergo seasonal variation across standard testing situations with increased winter and decreased summer heat loss. Most of these studies are reported and/or reviewed in;

Burton and Edholm (1955), Carlson and Hsieh (1965), Hampton (1969), and Krog et al. (1960). Of these studies, only two found decreased winter heat loss (Hampton, 1969; Wood, Bass, & Iampietro, 1958).

This writer does not feel justified in making a statement concerning the persistence or stability of Caucasian hand adaptation on the basis of available evidence. The reason is best illustrated with Budd's Antarctic studies. In this case, the increased susceptability to cold which followed a six week sojurn to summertime Australia could represent; seasonal variation, the decline of whole body adaptation, the decline of hand adaptation, diet changes, or some unknown combination. Clearly, a longitudinal study involving prolonged environmental changes within subjects is required before a clear statement can be made on either the persistence or stability of hand adaptation.

2.5.2.10 Heat Loss Due To Adaptation

LeBlanc (1962) measured simultaneously the total heat flow from the warm, adapted, hands of Gaspe Penninsula fishermen and cooler, unadapted control hands. This procedure ruled out seasonal variation. Figure 2-3 shows the relationship between immersed hand volume and heat loss in the fishermen and controls in a 5*C waterbath (LeBlanc, 1962). In this study the increase in hand temperature of roughly 2*C to 3*C appears to have cost roughly 2,000

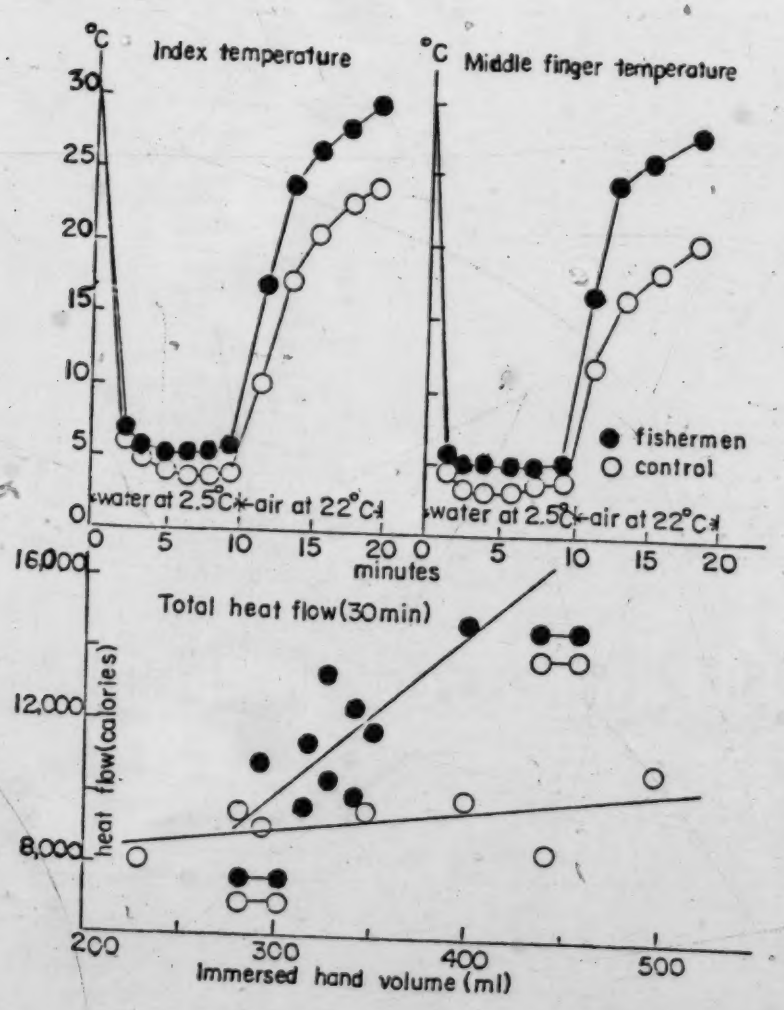


Figure 2-3

Variations in skin temperatures of index and middle finger and correlation between immersed hand volume and heat flow in Gaspe fishermen and control subjects during immersion of the hands in a water bath at 5 degrees Celsius. (from LeBlanc, 1975)

calories for a 30 minute period. The thermal expense of warmed hands was greater for large hands and less for small. In terms of organismic equivalence, 2,000 calories/half hour is roughly equivalent to the amount of heat generated by a very slow walk or stroll.

2.5.3 Primitive Hands

It should be recalled that most primitive peoples exhibit a style of whole body adaptation which is appropriate to the climate in which they have lived for centuries. The same is true of hand adaptation styles.

Hand adaptation in the naked and semi-clothed primitives involves primarily pain habituation. Hammel's (1960) study of the Alacaluf Indians provides typical findings. He immersed the hands of Alacalufs and Whites in 5*C water (Initial temperature) for 30 minutes and compared heat loss. Although he found greater variability of Alacaluf heat loss, there was no difference between total White and Indian heat cutput. Whites experienced the usual intense pain. The Indians reported no pain or even discomfort. This was not surprising to Hammel who had often observed them standing barefoot or playing in 5*C water. In general, one would not expect to find special hand temperature adaptations in the occupants of climates which are thermally adequate to support some degree of year around whole body exposure.

Primitive residents of severe climates such as the

Eskimos and Arctic Indians can not survive without some degree of hand exposure. In terms of evolutionary advantage one would expect to find hand adaptation mechanisms that allow them to deal with that exposure.

Before considering hand mechanisms, one should recall the state of northern Indian and Eskimo whole-body adaptation. In general, the Indian is not different from the non-adapted Caucasian in terms of BMR, as well as thermal and metabolic responses to overnight cold exposures both in the spring and the fall. The Eskimo has a hgher BMR than the Caucasian, although this is probably a dietary effect. Shivering onset occurs at the same temperature in Eskimos and Caucasians. The general pattern of response to prolonged whole-body cooling is the same for Eskimos and non-adapted Caucasians. Hand responses to cold however are very different.

Indians and Eskimos maintain warm hands in cold settings. Elsner, Nelms, and Irving (1960) for example, used 5*C (initial) immersions to compare hand heat loss of Arctic Indians to Caucasians in both warm body and cold body settings. They summarized their results as follows:

> Generally, the Indians showed a markedly superior ability to maintain hands warm in cold water. Their hands transferred more heat to the water whether the subjects were comfortably warm or chilly. In the cool environment hand heat loss was reduced in both groups, but the calculated heat transfer from circulation alone was still about twice as great in the Indians. The skin temperature measurements reflected the general trends of hand cooling and rewarming. The Indians withstood the hand immersion in ice water with quicker rewarming and less pain than the whites. Although their response is not

> conserving of metabolic heat, the loss is apparently trivial. The warming of the Indians' hands appears therefore to be adaptive in nature. (Page 662)

Many studies have reported qualitatively similar results both for Eskimos and for other Indian samples (c.f. Milan, 1962).

Indian and Eskimo hands, like adapted Caucasian hands, show a decreased rate of initial vasoconstfictiоn followed by the earlier onset of CIVD. As shown in Figure 2-4 the magnitude of CIVD is also substantially higher in Eskimo than in Caucasian controls.

Figure 2-5 from Eagan (1963) compares the temperature responses of adapted and un-adapted hands to Indian hands. The earlier onset and higher rate of Indian (like Eskimo) CIVD is apparent. It is interesting tc note that both adapted and un-adapted Caucasian hands follow the same initial CIVD pattern. The adapted hand temperature, however continues to climb until it approximates the Indian response. It should also be noted from Figure 2-5 that the Indian hands underwent two CIVD hunting cycles in the same time as the Caucasian hands underwent one.

In every published study reviewed by this writer Indians and Eskimos (like adapted whites) reported sensations of cold but no pain upon hand immersion in cold water (cf. Burton & Edholm, 1955; LeBlanc, 1975; Milan, 1962).

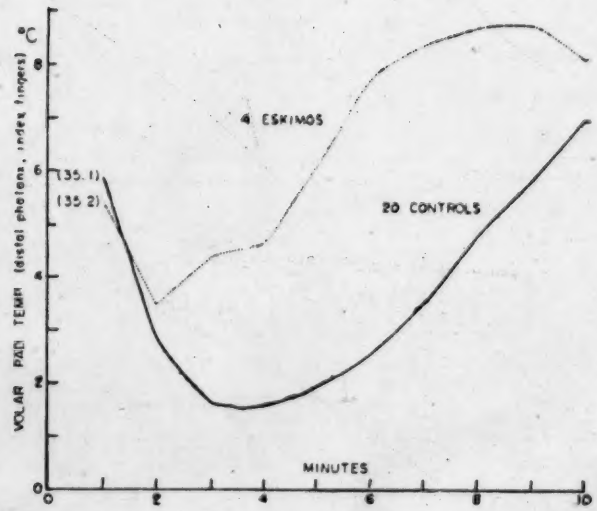


Figure 2-4

Comparison of group averages of temperatures of fingers during immersion in 0 degree Celsius water under standard test conditions (pre-immersion finger temperatures are shown in brackets.) (redrawn from Eagan, 1963)

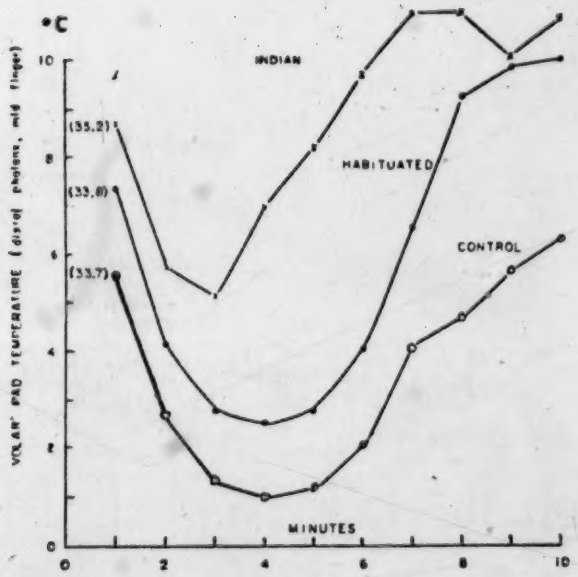


Figure 2-5

Averaged responses for three groups (six subjects in each) during immersion of fingers in 0 degree Celsius water under standard test conditions. (from Eagan, 1963)

Eskimos maintain their warm hands over long exposures without thermal ill-effects. Brown, Bird, Boag, Boag, Delahaye, Green, Hatcher, & Page (1954) for example, found continuous hand warming through two hours of cold water immersion with no deleterious effects on the subjects. In addition to the direct temperature benefits, Brown et al. (1954) reported that warm hands permitted great hand efficiency in the cold. Specifically, they observed the Eskimo's ability to work with bare hands and to continue to perform fine movements over extended periods in the winter cold. It should be noted here that the intent of the present study is to bring about thermal hand effects which are similar to the Eskimo's and to investigate whether parallel dexterity and pain effects occur.

2.6 Summary

Chapter two began with a discussion of the behavioral and physiological mechanisms which permit organismic survival during cold exposure. Emphasis was placed jointly on increased insulation by decreased peripheral circulation and on shivering thermogenesis as the major protective mechanisms. The notion of organismic adaptation by increased thermal capacity was introduced along with a discussion of the reasons why few humans ever achieve more than the beginnings of this state.

Human adaptation was shown to consist primarily of reduced emotionality through central nervous system

habituation, accompanied by a marked reduction or termination of shivering thermogenesis and cold pain. The usual thermal cost of this adaptation was mild core hypothermia. Further, human adaptation was shown to be; slow and painful to develop, of small magnitude in the early stages, variable, and rapid to dissipate. Indian and Eskimo whole-body adaptation was shown to be qualitatively similar to White adaptation but with greater basal metabolic rate (BMR) and physical fitness as well as less body fat.

A discussion of the major organismic variables known to influence cold hand functioning included; body size and shape, sub-cutaneous fat, physical fitness, sex, chemical and emotional vasoactive agents, diets, and diet supplements.

The phenomena of cold induced vasodilation (CIVD) and the "hunting reaction" were introduced and discussed as vascular occurrences in non-adapted hands. The roles of arteriovenous anastomoses and other circulatory structures were discussed as the effectors underlying both phenomena.

Adapted Caucasian hands were shown to be warmer than non-adapted hands as a result of less intense initial vasoconstriction accompanied by the earlier onset and increased reactivity of CIVD upon cold exposure. The result of adaptation was a reduction in pain and the cold pressor response as well as greater hand efficiency. Different aspects of hand-adaptation control were shown to occur both in the central nervous system and in local humoral, neural,

and somatic tissues. The acquisition, nature, and persistence of hand adaptation were discussed. Some small degree of Caucasian hand adaptation was found after as little as three weeks exposure although a much longer exposure appears necessary to get a strong and generalizable effect. Even in fully adapted hands, the circulatory effects were found to undergo daily and seasonal variation. Little clear evidence was available on the persistence of the effect following extended periods of warm exposure. The thermal expense of hand adaptation was seen to be minimal (negligible to a physically fit person) with no deletereous effects to the organism.

The literature showed the adapted hand to be more efficient in the cold. In general, adapted hands were stronger, more sensitive, more dexterous, and less subject to pain than non-adapted hands. The even warmer Indian and Eskimo hands were seen to permit very fine movements even after extended, bare-hand, outdoor work. Although Indians and Eskimos lose more heat from the hands than Whites this loss is homeostatically trivial given otherwise warm clothing.

The reader may find Figure 2-6 (substantially changed after Eagan, 1963) to be a useful aid in organizing and relating many of the variables discussed above. Figure 2-6 does not add new information but is included with the hope that it may aid in semantic organization and recall. The dotted lines and enclosures represent the hypotheses to be

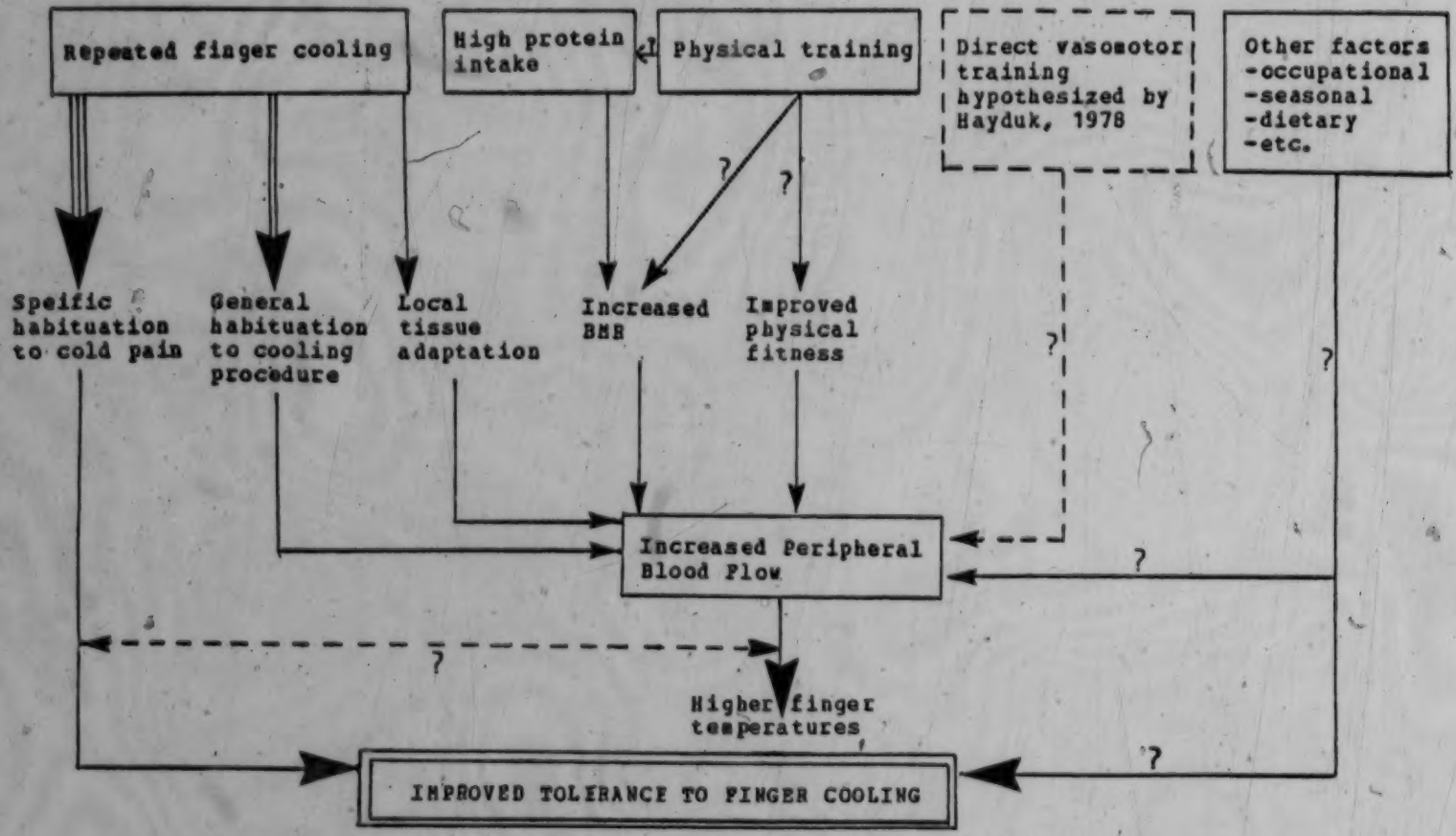


Figure 2-6 Factors affecting tolerance to finger cooling under basal conditions. (Broken lines represent the hypothesized factors from the present study.) (Substantially adapted from Eagan, 1963)

investigated by the present study.

3. VOLUNTARY CONTROL OF VASOMOTOR ACTIVITY

3.1 Overview

It is well known that peripheral vasomotor activity can be controlled. Such control has been achieved directly by classical conditioning, relatively directy by operant conditioning and cognition (hypnosis, imagery, autogenic training etc.), as well as indirectly through the effects of somatic manipulation (Yoga, breath control etc.). Control over vasomotor events is most easily achieved and the effects may be most pronounced when two or more types of treatment are combined. In the present study, the treatment is composed of timed and sequenced components drawn from classical conditioning, operant conditioning and cognition.

This chapter begins with a review and a discussion of classical vasomotor conditioning in the West and in the USSR. The relative ease and permanence of training, and the powerful vascular effect are discussed along with the failure of western temperature trainers to incorporate classical conditioning components in their primarily operant paradigm. Operant training of hand temperature is reviewed and discussed followed by the related issue of cognitive vasomotor control. Integrated and combined studies which have examined the relationships and interactions of classical, operant, and cognitive temperature control are discussed next. The "treatment package" used in the present study is then discussed as a specific combination of

classical conditioning, operant conditioning, and cognition. The chapter closes with a restatement of the purposes of the study and the listing of specific predictions to be tested.

3.2 Classical Conditioning Of Hand Blood Flow

3.2.1 Definition

Classical conditioning involves the joint presentation of a neutral stimulus such as a bell (CS) with a stimulus (such as cold water) that elicits a change in hand circulation (US). After repeated pairings, the previously neutral stimulus (bell) is presented alone. When it reliably elicits a hand vasomotor change (in this case vasoconstriction), classical conditioning is said to have occurred. If both the CS and the US occur extradermally the process is exteroceptive classical conditioning. If the CS and/or the US occur internally the process is one variety of interoceptive classical conditioning (Razran, 1961).

3.2.2 Stimulus Considerations

Western studies have typically conditioned hand vasoconstriction both because it is more reactive than vasodilation and because it can be easily elicited by any stimulus which repeatedly commands attention, causes pain, or poses threat value. Most western studies for example, have used electric shock to the hand or wrist as the US (Baer & Fuhrer, 1970; Gottschalk, 1946; Roessler & Brogden, 1943; Shmavonian, 1959; Teichener & Levine, 1968) although

Cytovich and Folkman (1917 in Menzies, 1937) and Menzies (1937, 1941) used repeated immersion of one hand in ice water. Marienesco and Kreindler (1943 in Menzies, 1937) used the prick of a needle.

Western researchers have used a wide range of individual and combined CS in vasomotor conditioning (bells, lights, tones, patterns, posture, etc.). Although some conditioning is typically achieved with a single CS, stimulus summation facilitates vascmotor conditionig, particularly when one of the CS is a verbal utterance (Menzies, 1941; Roessler & Brogden, 1943). Further, there is substantial evidence that cognitive factors are also additive with exteroceptive CS. Gottschalk (1946) for example questioned his subjects and found that those subjects exhibiting greater insight into the conditioning procedures achieved greater conditioning. Similarly, Baer and Fuhrer (1970) found vasomotor conditioning to a single stimulus to occur only in those subjects who were able subsequently to verbalize the CS-US relationship and Shmavonian (1959) found that no conditioning occurred to a single tone unless the US was sufficiently intense to arouse emotions.

3.2.3 Response Considerations

3.2.3.1 What Is Conditioned

Because the present study involves classical conditioring of vasodilation, not vasoconstriction, it is

necessary to show that the hand vasomotor conditioning which appears to happen in most western studies is vasomotor conditioning per se. and not simply a small part of some multi-dimension conditioned shock response (Lynn, 1966) or one of the lesser known autonomic responses that occurs in response to mild auditory, visual, and tactile stimulation (Davis, Buchwald & Franklin, 1955). Two studies have provided relevent evidence. First, Shmavonian (1959) showed a clear lack of correlation between vasomotor conditioning and three other orienting and defensive reaction indices. Second, in a classically serendipitous study, Teichner and Levine (1968) used a tone-shock combination to condition hand vascmotor responses in semi-naked subjects. Seven subjects trained in a hot (90*F) room and seven others trained in a cold (55*F) room. Unexpected vasodilation instead of further vasoconstriction was found in all cold trained subjects. Since hand vasodilation is not a component of the orienting, defensive, or startle reactions it is clear that in this case the shock induced vasomotor activity was not a part of one of these reactions. Teichner and Levine suggested that what is actually trained in the classical conditioning of hand vasomotor activities is a tendency for vasomotor reaction. The expression of this tendency would be either dilation or constriction depending on the momentary state of organismic heat regulating mechanisms and peripheral blood flow. Unfortunately, their suggestion has not been verified by training

vasoconstriction in a warm room and then measuring the thermal reaction when the CS is presented alone in a cold room.

3.2.3.2 Response Characteristics

In almost all respects classically conditioned hand vasomotor responses are typical of classically conditioned responses in general. The CR begins 2 to 3 seconds after the CS presentation (Shmavonian, 1959) and lasts approximately 30 seconds (s.d.=17 seconds) (Menzies, 1937). Skin temperature decrease upon CS presentation is approximately 3/4 as great as upon US presentation (Menzies, 1937).

Conditioned hand temperature responses are atypical in that they are highly resistant to extinction. Menzies (1937, 1941), Shmavonian (1959), Teichner and Levine (1969), and Gottschalk (1946) all found decreased response amplitude over the first four to six extinction trials followed either by a complete leveling off or only a small decrement in response over many trials. Surprisingly, a number of subjects have shown continued increases in response amplitude over extinction trials (Gottschalk, 1946). Russian investigators of the classical conditioning paradigm appear to have proposed the most likely explanation for this phenomena.

3.2.4 The Russian Perspective

Russian researchers of the classical conditioning

paradigm have proposed three major principles of interoceptive classical conditioning in humans that are of particular interest to the present study.

First, Markov (1950 in Razran, 1961) demonstrated that effective vasomotor classical conditioning can be achieved without the subjects awareness by using an unperceived interoceptive CS such as mild visceral electric shock. (The reader should recall here that awareness was a necessary component in the western studies where exteroceptive CS were used.) Further, Markov's finding is clearly consistent with the western view on the mechanisms of emotional conditioning in humans (cf. Miller & Dollard, 1941; Watson & Rayner, 1920).

Second, semantic stimuli may be used as interoceptive stimuli (Okhnyanadaya in Razran, 1961). Okhnyanadaya, for example found that deep inhaling reliably elicits hand vasoconstriction. He then demonstrated that a similar vasoconstriction is elicited by presentation of the Russian word for "inhale" at times when breathing is stilled. Further, classically conditioned semantic stimuli show greater generalization along semantic than verbal-acoustic dimensions. Razran (1961) reviewed six major classes of Russian experiments which have investigated this phenomena and concluded that semantic generalization occurs both consciously and unconsciously in complex relationships with other non-meaning units in such a way that cognitive linguistic (and perhaps imaginal) control can be achieved

over classically conditioned phenomena. Semantic stimulus generalization decrement has been demonstrated in humans for: vasoconstriction, vasodilation, blood clotting rate, and many other dimensions of less direct interest to this review (Razran, 1961).

Third, interoceptive conditioning is far more resistant to extinction than exteroceptive conditioning. Further, when an interoceptive CS is used as the US in higher order conditioning the resulting habit is also relatively stable and resistant to extinction (cf. Razran, 1961). This finding likely explains the very slow extinction of conditioned vasomotor activity reported earlier by western researchers, in that ccgnition appears to have acted as a subject-supplied interoceptive adjunct to the experimentally provided exteroceptive CS.

In summary, vasomotor responses may be classically conditioned. Depending on the specifics of the training situation conditioning is rapid, relatively permanent, and under the voluntary control of the client. In a later, integrative, section it is shown that classical conditioning may be used effectively with operant techniques. Never-the-less, western researchers and practioners seldom investigate or incorporate classical conditioning in vasomotor studies.

3.3 Operant Conditioning Of Hand Blood Flow

3.3.1 Definition

There is general agreement that humans may control their peripheral blood flow when they are provided with ongoing information about the state of their peripheral circulation. There is not general agreement (and little concern) as to whether this control is best explained by an operant, instrumental, or cybernetic model. Unfortunately, many writers have used these terms interchangeably so that they have become relatively meaningless in much of the literature. Worse, all three terms are commonly equated with the popular press term "biofeedback". The present writer uses the term "operant" throughout because many of the studies reviewed below have incorporated possible reinforcement contingencies. This does not, of course, rule out the possibility that a cybernetic model best explains the control which follows from the external afferentiation of biological information or that the operant paradigm is confounded with classical conditioning or cognition.

3.3.2 Paradigm Development

The operant training of vasodilation was first demonstrated by Lisina, a Russian worker, in 1961 (Razran 1961; Lisina, 1965). She subjected her five subjects to continuous dermal electric shock which produced strong vasoconstriction accompanied by occasional brief bursts of vasodilation. Shock was terminated immediately following the

onset of spontaneous vasodilation. No training occurred after 80 such terminations. Lisina subsequently increased the discriminability of the vasomotor responses by allowing the subjects to watch the plethysmograph as it recorded changes in blood flow. Following the introduction of this clear circulatory information (or feedback) all subjects learned to terminate the shock by replacing vasoconstriction with vasodilation. This study demonstrated first that blood flow can be modified by its consequences and second, that cognitive mediation is necessary for such modification (Buck, 1976; Razran, 1961).

By 1968 Snyder and Noble had demonstrated wholly operant control of finger vasoconstriction. Their subjects learned to increase the frequency of vasoconstrictive episodes when a light was used to signal a decrease in finger pulse-volume amplitude below a criterion value. Further, once the initial learning had occurred the subjects were gradually weaned from the machines with no loss in strength of their new response. These two studies contain all the basic elements of operant vasomotor control.

First, in operant vasomotor control, a change in vasomotor activity occurs. Some dimension of that change is monitored. The monitored change is amplified, adjusted, and then presented to the subject in some usable form. The subject uses the information to achieve voluntary control of the initial vasomotor aactivity. Finally, the subject is weaned from the machine but continues to exhibit voluntary

control of the trained vasomotor reaction.

3.3.3 Response Parameters In Operant Training

Taub (1977), and Taub and Emurian (1976) have conducted a series of studies to determine the range of operant temperature control which may be achieved in humans, as well as the conditions and variables which affect the attainment, magnitude, and persistence of that control. In their initial study, 21 subjects attempted to alter hand temperature in the oppcsite direction of the baseline trend. Ninteen subjects succeeded. The average temperature change for the whole group was 2.2*F (range, 0-6.5 F*) over the final three sessions of six, 15 minute training periods.

The seven best regulators subsequently received additional training in reversing the direction of temperature control. After this second training phase, each of the subjects changed hand temperature in either direction, upon request, with temperature increases of up to 14F*. The most rapid change was 9 F* in one minute. Hand temperature returned quickly to baseline when the subjects were asked to relax.

Taub and Emurian found hand training to be robust and relatively permanent once it had been achieved. For example, Taub (1977) and other workers in his laboratory (Wand, Slattery, Haskell & Taub, 1977) found a restricted anatomical specificity of the self-regulatory effect when feedback was provided from a single point. In some cases

voluntary skin temperature changes at the training point did not produce temperature changes just 2 cm away. Fortunately, the transfer of specific training to other hand locations appears to be easy and rapid (Taub, 1977). An alternate and slower method of whole-hand training which may be used if necessary is to provide feedback from five separated sensors simultaneously during the initial training (Taub, Emurian, & Howell, 1974).

It should be noted that anatomic specificity has not been found in hand temperature training in the many studies which used combined feedback and autogenic phrases for treating migraine headaches (Damond & Franklin, 1974, 1975; Drury, DeRisi, & Liberman, 1975; Glaadman & Estrada, 1974; Mitch, McGrady & Iannone, 1975; Pearse, Sargent, Walters & Meers, 1975; Peper & Grossman, 1974; Sargent Green & Walters, 1972, 1973; Turin, 1975; and Wickramasedera, 1973). Taub (1977) suggested that a possible explanation for this difference is that his work represents specific vascular conditioning of the hand while temperature changes in the headache studies are side effects of whole-body relaxation (Taub, 1978). An alternate interpretation is that the headache groups achieved cognitive control of hand temperature based on imagery. In this case, the feedback would function as an adjunctive treatment in "sharpening" the whole-hand response of this qualitatively different mechanism (Hayduk, 1978). Support is offered for Hayduk's position by the series of studies which used operant

feedback conditioning to treat Raynaud's disease.

Raynaud's disease is a painful disorder of the peripheral vascular bed in which blood flow to the hands and feet is severely reduced by involuntary and prolonged spasms of the arteries and arterioles in response to cold or emotional factors. With one exception (Peper, 1973) many studies have shown Raynauds patients to bring their hand temperature into the 'normal' range after 15 to 30 feedback training sessions (Blanchard & Haynes, 1975; Freedman, Lynn & Ianni, 1978; Jackobson, Hackett, Surman & Silverberg, 1973; Surwit, 1973; Taub, 1977). For most of these patients voluntary hand warming led to a decreased frequency and intensity of Raynauds attacks. Within these studies, Taub was the only researcher to use multiple locus feedback. Never-the-less, the patients in all the studies reported whole hand relief. That would not likely have been the case if the training effect had been restricted to the initial training site. It is probably most appropriate to consider Taub's anatomic specificity of training as a clear demonstration of the precision which may be achieved but which need not be an hindrance to whole hand training provided multiple site feedback or cognitive variables (discussed below) are employed.

3.3.4 Hand Regulation At Cold Temperatures

There is some preliminary evidence that operantly trained subjects may continue to self-regulate hand

temperature in cold settings even though they have been trained in relatively warm surroundings. Taub (1977) collaborated with the Army Research Institute Of Environmental Medicine to conduct a series of preliminary experiments into possible cold weather application of operant vasomotor control. In his first study, three subjects whc could self-regulate hand temperature at 70 *F continued to do so when the temperature fell to 55 *F, even though they were lightly dressed. Further, the magnitude of the effect was enhanced in the cold chambers.

In a second study, the three subjects successfully raised their hand temperature after 25 minutes of cold exposure during which pronounced cold induced vasoconstriction had been allowed to set in before hand warming was started.

In a third study, one of the three subjects exhibited a more rapid and earlier (9 F* warmer) onset of CIVD when his finger was inserted into a "frost nip" apparatus. Results with the second subject were equivocal. The third subject did not participate.

In a separate cold-setting study, Taub's (1977) subjects demonstrated continued ability to maintain increased whole hand temperature while the opposite, untrained hand was immersed in 40 *F to 46 *F (painfully cold) water for 10 minutes.

Taub's cold study results have not been confirmed or disproven in any other reported studies. His results, by

themselves, are limited both by the very small number of subjects and by the fact that only "good subjects" were used. Never-the-less, they are encouraging for purposes of the present study because they demonstrate that learned hand blood flow mechanisms are capable of overriding organismic thermoregulatory mechanisms. Prior to Taub's studies, there was no direct evidence that evolved and adaptive thermoregulatory mechanisms were relatively weak enough to be changed by instruction in an organismically stressing situation.

3.3.5 Negative And Equivocal Findings

Several recent and well controlled studies with non-selected and randomly assigned subjects have found less pronounced ability to increase hand temperature in the operant feedback setting. Surwit, Shapiro, and Feld (1976) found a mean temperature increase of .25 C* in eight subjects over seven or eleven operant feedback sessions with the best controllers able to increase by approximately 3.5 C* per session. To rule out a ceiling effect (most of the subjects hands were at or near room temperature) Surwit et al. re-ran the temperature increase portion of the study in a cooler (19.5 *C) room. No subjects were able to learn control in this 3 *C cooler setting. All subjects in this study achieved rapid and clear control of vasoconstriction.

A second study by Surwit (1977) also found subject inability to vasodilate. Learning was not enhanced by using

a more complex feedback system.

Surwit et al. (1976) suggested that operant hand temperature increase may be an artifact of the orienting reaction in combination with inadequate baseline procedures. From this perspective the experimental context would produce an orienting reflex complete with finger vasoconstriction and cold digits. The apparent control of hand warming following a too-short baseline would then consist of habituation to the orienting stimulus accompanied by warming of the fingers. Warming could then be attributed, wrongly, to operant learning. Although this process could account for studies showing small, unidirectional changes, it does not account for the rapid and substantial bi-directional control exhibited by Taub's subjects, since habituation would occur slowly and is not a voluntary, on-off process.

A more likely explanation for the difference between successful and unsuccessful vasodilators is baseline hand temperature because people with a baseline hand temperature at or near core temperature could not possibly increase their hand temperature further. (Individual hand temperatures in normals ranges from 21 *C to 37 *C (Boudewyns, 1976)). Lowering the room temperature to lower the hand temperature before training (as in the Surwit et al. studies) however may invoke superordinate thermoregulatory mechanisms (including hand vasoconstriction). Operant training of temperature regulation would then become impossible because no

vasodilative episodes would occur to be reinforced. This possibility is strongly supported by the relative success in training Raynauds patients to bring their hand temperature from very low into the normal range although few of them ever achieve very hot hands.

Hayduk (1978) has suggested the use of an elicitied-operant paradigm (classical-operant overlap) in a cold training setting to investigate the possible ceiling effect in hand temperature training so as to extend biofeedback treatment to migraine and Raynauds patients who have warm hands in warm settings. That is, a vasodilative CS would be presented within a cold setting and thus elicit a brief vasodilative episode which could, in turn, be monitored and reinforced in the operant conditioning paradigm. (The logic of this approach is very similar to the present study.)

Support for such a position was offered by Neil Miller (1978) who reviewd a classical-operant overlap study of trained heart rate deceleration (Freudy & Poulos, 1970) and suggested the clear need for further investigation of this paradigm, particularly for circulatory and cardio-vascular events.

In addition to ceiling effects, the interpersonal climate between subject and experimenter has been shown to have a clear effect on temperature training results in three studies (Leeb, Fahrion & French, 1974; Russell in Taub, 1977; Taub, 1977). In each case, clinical, or impersonal

experimenters did not train increases in hand temperature while confident, friendly, and informal experimenters succeeded in training subjects. This finding is probably a procedural restatement of the well known effects of emotions on hand temperature and circulation (cf. Chapter 2 and below in this thesis; Crawford, Friesen & Tomlinson-Keasey, 1977; Burch & Thorpe, 1948; Taub, 1977).

In summary, vasomotor responses may be operantly conditioned. Depending on the specifics of the training situation, training is : substantial, rapid, relatively permanent, and under the voluntary control of the client. The anatomical effect may be general or precise. In a later, integrative section it is shown that operant conditioning may be used effectively with classical conditioning and cognitive techniques.

3.4 Cognitive Control Of Hand Blood Flow

It is well known and widely accepted that cognitive events can be manipulated to produce marked changes in peripheral circulation patterns and in tissue perfusion. Unfortunately, most evidence of voluntary changes in hand temperature and blood flow has been collected during specific partisan investigations and the results have not been published in easily comparable form. In many cases, even specific temperatures have not been reported. As a result, integration and analysis of the cognitive hand-circulation control literature is difficult and no

single review paper has been published.

The hand circulation changes summarized in Table 3-1 occurred in response to a wide range of cognitive induction techniques. The group of attitude change studies performed by Graham and his associates (items 8, 9, 11, 12, 13) demonstrated that normal people exhibit appropriate skin temperature and perfusion changes as they receive instructions (both hypnotic and simple instructions) to take on attitudes which are typical of people who suffer skin diseases such as; psoriasis, exzema, Raynaud's disease, and hives. Most of the reported temperature changes were very small (approx. 0.1 *C) and required relatively complex induction techniques. They offer little to the present study in terms of magnitude of effect per unit of effort and thus are not discussed further.

The remaining studies report substantial thermal changes. Although they appear diverse, for the purposes of this study it is not necessary to consider the theoretical underpinnings, specific practices and epistemological assumptions which underlie their diversity. Instead, four across-groups procedural commonalities are considered. Practitioners of hypnosis, auto-hypnosis, auto-suggestion, and meditation are usually deliberately trained in; 1) deep muscle relaxation, 2) concentration, 3) vivid imaging, and 4) dissociation from contextual stimuli (Arnold, 1946; Barber, Spanos & Chaves, 1974). Most practitioners of biofeedback, Zen, Yoga, and Autogenic training receive

Table 3-1

Studies Investigating Hand Vasomotor Control In Response To Cognitive Manipulations

Theoretical perspectives are coded: Autogenic Training (A), Induced Emotional States (E), Induced Attitude Change (IA), Hypnosis (H), Suggestion (S), Meditation (M), Temperature change command (T), Yoga (Y), Imagery (I). Studies including imagery are marked (*). Studies followed by "biofeedback" are marked (B). "( )"indicate range.

No.	Authors	Hand Temp. Increase	Hand Temp. Decrease	Theoretical Perspective	N	Comments
1	Edwards, 1915 in Arnold, 1917	clear sensation		S *		In response to "expected" warm command
2	Hadfield, 1917	hyperimia, pain, blister	decreased hyperimia	H *	1	
3	Hadfield, 1920	/26 F*	5F*/27F*	T:S *	1	Before exercise/ after exercise
4	Schultz, 1926 in Luthe, 1965	2 C*	Substantial 1 case vaso-spasm & cold pain	A *		passive volition only
5	Menzies, 1937	1 S vaso-dilation	3 S vaso-constriction	*	4	Imaging CS following classical conditioning of temp. decrease
6	Mittlemann & Wolff, 1939		2.2-13.5 C*	E	8	8 emotional parameters (mood)

Table 3-1: Continued

No.	Authors	Hand Temp. Increase	Hand Temp. Decrease	Theoretical Perspective	N	Comments
15	Harano, Ogawa & Naruse, 1965	substantial	not attempted but found with active volition	A *	20	increase in passive volition only
16	Luria, 1969	2 C*		I *	1	
17	Bagchi & Wenger, 1971		1.0 *C	Y:M	4	severe body manipulations
18	Wenger, Bagchi & Anand, 1971		x	Y	4	elimination of peripheral pulse, severe contortions
19	Maslach, Marshal & Zimbardo, 1972	2 F*(d)	(2-7)F* (d)	H	6	(d)difference between hands, no change in controls
20	Roberts, Kewman & McDonald, 1973	(.2-.5)C* (d)	(.2-.5)C* (d)	H:M:B	6	(d) difference between hands, (d) elicited initial response
21	Crosson, Andreychuk, Tieman & Phillips, 1978	increased hand temp.		A:B:H *	7	hypnosis alone gave temp. change similar to biofeedback
22	Surwit, Pilon & Fenton, 1977	sig. p<.003		A:B	30	Raynauds population, ambient temp. decr. from 26 C* to 17 C*

Table 3-1: Continued

No.	Authors	Hand Temp. Increase	Hand Temp. Decrease	Theoretical Perspective	N	Comments
7	Menzies, 1941	temp. change	Temp. change	*?	22	recalling previously experienced hot & cold conditions
8	Graham. 1955	no	X=.8 *C (.3-1.2)	E:IA	19	skin disorder patients i.e., Raynauds Psoriasis
9	Graham, Stern & Winokur, 1958	X=.1 *C	X=.29 *C	H:E:IA	24	hives, Raynauds attitude
10	Wenger & Bagchi	moderate		Y:M	1	6 months practice in cold temp., incr. sensation of warm, decr. pain, forehead perspiration
11	Stern, Winokur, Graham & Graham 1961	max=.5 C*	max=.2 C*	H:E:IA	22	attitude: hives Raynauds, hypertension
12	Graham, Kabler & Graham, 1962	X=.1 C* max=.2 C*	X=.1 C*	E:H:IA	20	disease-specific attitude
13	Graham & Kunish, 1965	(.08-.19) C*		E=20 H=40	60	IA - hives, hypertension
14	Ikemi, Nakagawa,	X=2.5 C*	not	A *	35	passive volition

Table 3-1: Continued

No.	Authors	Hand Temp. Increase	Hand Temp. Decrease	Theoretical Perspective	N	Comments
23	Taub, 1978	(1.75-3) F* a b		H:S *	1	initially unable to regulate with biofeedback (a=hypnosis alone) (b=hypnosis plus biofeedback)

similar training although it may be incidental to the focus of their efforts (Libo & Femhi, 1977; Onda, 1965). Three of these four factors have direct thermal concomitants.

Relaxation or tension can induce increased or decreased hand temperature, particularly in anxious patients (Boudewyns, 1976; Crawford, Friesen & Tomlinson-Keasey, 1978). Concentration alone can lead either to increased or decreased hand temperature (Harano, Ogawa &Naruse, 1965). Column 5 of Table 3-1 shows that imaging was a factor in almost all of the non-attitude cognitive temperature control studies. In eight of these studies (items 2, 3, 4, 5, 7, 10, 16, 23) imaging alone was sufficient to produce thermal changes. It is not clear whether "dissociation from contextual stimuli" has any direct thermal effect although it is very likely an indirect variable which supports relaxation, concentration, and imaging.

In summary, there is no doubt that cognitive processes maybe used to control vasomotor activity although the effects are best with "good subjects" and/or sustained practice. It has been reported above that cognitive factors are an important component in the classical conditioning of hand temperature. There is even greater evidence that cognitive factors are central in achieving operant control of hand temperature. Because the present study uses a combined treatment based upon aspects of classical conditioning, operant conditioning, and cognition, the inter-relationship of these variables is discused further

below, under the rubric of 'Combined Studies'.

3.5 Combined Studies

In practice with normal subjects, it is probably impossible to isolate the absolute thermal effects of cognition, classical conditioning,and operant conditioning. The very recent studies discussed below, have provided preliminary data on the relational and propcrtional effects of these three ccmponents.

3.5.1 Cognition And Feedback

Libo and Femhi (1977) investigated the cognitive strategies used in achieving operant hand temperature control by 40 subjects drawn from geograghically isolated areas and trained with different feedback methods. Almost all successful subjects began training with vivid thermal imagery involving warm or swollen hands. As training progressed, approximately half switched to secondary strategies which are reminiscent of a passive, hypnosis or meditation like state. Typical secondary strategies reported tc Libo and Femhi were:

> not thinking of anything, mind blank, getting into it and going with it, losing self in prayer, seeing a beautiful Mass, letting the mind wander onto pleasant things, just concentrating on the tone, imagining the tone going faster, gcing deep into myself and finding peace and quiet, going into the depths of my body, going into darkness, ... leaving my body, just floating, my head just floating.... (page 4)

This study suggests that some aspect of cognition is used by almost every successful subject whether or not such strategies are suggested by the experimenter. In this vein, Keefe (in press, in Taub, 1977) found that providing specific instructions to subjects greatly facilitated early learning although some uninstructed subjects could eventually produce similar results if the training series was greatly extended.

Crosson, Andreychuk, Tiemann, and Phillips (1978) compared hypnosis, autogenic phrases, and operant feedback in the treatment of migraine by hand temperature increase. They found the cognitively oriented hypnosis treatment led to physiological changes similar to those obtained with biofeedback. They concluded that the interaction between cognitive and physiological factors may be central in the treatment of migraine.

Surwit, Pilon, and Fenton (1978) successfully treated 30 Raynauds disease subjects using one of; a) autogenic treatment at home, b) autogenic treatment in the lab, and c) autogenic treatment plus feedback. All groups did better than the controls. Further, "there was no clinical advantage for subjects receiving biofeedback in addition to autogenic training or labcratory as opposed to home training."

3.5.2 Classical Conditioning And Feedback

In a study of particular interest, Keen and Montgomery (1978) used interoceptive reinforcement (a warm light) in

thermal training facilitated by an elicited-operant paradigm (49 subjects). The US was hand immersion in either hot or cold water. Both the interoceptive feedback, and the elicited-operant experimental groups obtained significantly better temperature increases than the "meter only" group. The "meter only" feedback group, in turn, did better than the controls.

In summary, Libo and Femhi demonstrated that congnition is almost always a central component in biofeedback hand temperature training. Crosson et al. showed that the effects of cognitior and feedback are additive and some advantages accrue from specifically manipulating the cognitive variables. Indeed, for some conditions, cognitive manipulation may be as important as feedback (Surwit et al., 1978). Finally, Keen et al. (1978) showed that the effects of classical conditioning, operant feedback, and interoceptive reinforcement are additive in at least some combinations. Their study supports Lisina's (1961) demonstration of the utility of an operant-respondent overlap design in teaching vasodilative control.

3.6 Review Summary

In total, the studies immediately above support the general theme of the present chapter. That is, hand temperature increase can be trained by using any one of; cognitive variables, classical conditioning, or operant control, although unspecified cognition of some sort appears

to be necessary for both conditioning types. In most cases, vasomotor effects are more pronounced and more rapidly achieved in multiple applications. Further, multiple or sequential applications are more likely to produce changes in people who might not respond to any single treatment.

3.6.1 Experimental Treatment

The treatment used to establish voluntary control of hand vasodilation in cold settings in the present study was a logically sequenced combination of components from classical conditioning, operant conditioning, and cognition. The training sequence is most easily considered in six sequential steps. First, the conditioning components of the experimental procedure were explained to the subject until he could correctly paraphrase both the CS-US relationship (Baer & Fuhrer, 1970) and the rationale underlying operant vasomotor conditioning (Libo & Femhi, 1977). This step included the subject's selection of a personally meaningful and appropriate thermal image.

Second, the subject entered a cold chamber (-10 *C) with only his face and hands exposed. An effort was made to create an unhurried and relaxed atmosphere throughout the entire procedure. Hand temperature (index finger, volar pad) of one hand was monitored until vasoconstriction was clearly established and stable (no further decreases in temperature for 1 minute). Third, the subject was asked to image his warm hand scene as clearly as possible. When the image

reached maximum clarity the subject pressed a button and said aloud the sound "WEK".

Within one second after the button press the monitored hand was flooded with warm water until evidence of strong vasodilation was seen (approx. 7 sec.). One to two minutes following the termination of the warm water, the warmed hand was cooled to baseline with a cold water flush and the entire sequence was repeated until the probe trials (11, 21, 30, 40) indicated clear evidence of classically conditioned vasodilation. (The criterion was sufficient vasodilation to allow monitoring for feedback in the subsequent operant conditioning paradigm.) Ten training trials past criterion were provided.

Fifth, a thermister was attached to the index volar pad and visual (zero center meter) and auditory (decreasing tone) thermal feedback was provided. He was then asked to raise his hand temperature as much as possible using his classically conditioned thermal response as a starting point. Operant training was continued until a clear and apparently unbreakable plateau was reached. Subjects were encouraged to "play around" with finger temperature throughout training to ensure maximum volitional control. As training progressed the subject was encouraged to move the fingers and perform simple manual dexterity tasks (bend paper clips, tie knots, solve ring puzzles) while simultaneoulsy maintaining high hand temperature. In order to avoid anatomical specificity of training the thermister

was moved to other finger pads and the web dorsum as training progressed.

Sixth, the subject was gradually weaned from the feedback until he could reliably produce and inhibit hand warming upon request and without any feedback at all.

The treatment may also be described in theoretical terms. Organismic thermoregulatory mechanisms were allowed to induce continucus vasoconstriction. Vasodilative episodes were classically conditioned using a bipartite CS with interoceptive and intero-exteroceptive elements (warm image, spoken sound). As a result of classical conditioning, vasodilative episodes became freely available events and hence subject to operant conditioning. Following operant training, feedback was gradually withdrawn leaving extended vasodilaticn under the dual control of eliciting cognitive stimuli (thermal image and "WEK") as well as cognitive and environmental reinforcers.

3.6.2 Predictions

The essence of the discussion above can be presented in two summary statements. First, within a cold environment, warm hands function more efficiently than cold hands. Second, people can be taught to warm their hands voluntarily. The primary hypothesis of the present study was that hand efficiency in the cold could be enhanced by training voluntary hand warming in the cold. Hand efficiency in this context was taken to mean; manual dexterity, finger

dexterity, hand strength, tactile sensitivity, and perceived cold pain. (Operational definitions are provided in Chapter IV, "Method".)

In addition, the relationship between hand warming and cold-induced vasodilation was investigated

These predictions may also be stated in subforms directly amenable to statistical testing:

1. Voluntarily warmed hands will be more dexterous than unwarmed hands in a standard cold test.
2. Voluntarily warmed fingers will be more dexterous than unwarmed hands in a standard cold test.
3. Voluntarily warmed hands will be stronger than unwarmed hands in a standard cold test.
4. Voluntarily warmed hands will be more sensitive than unwarmed hands in a standard cold test.
5. Subjective reports will indicate less cold pain in warm than in cold hands in a standard cold test.
6. Cold induced vasodilation onset will occur earlier in voluntarily warmed hands than in unwarmed hands.

3.6.3 Handwarming In The Cold And Educational Psychology?

It must be acknowledged at the outset that the content and possible results of the present study have many interdisciplinary connections. Variables drawn from; Engineering, Home Economics, Medicine, Pharmacology, Physical Education, Physiology, and Psychology had to be considered prior to the design of the present study. Further, the theoretical implications and possible direct

applications extend even beyond the boundaries of these fields into industry, the military, sports, and much outdoor northern activity. It is important, however, that the treatment process being investigated and developed in the present study should not be confused with the possible uses of the treatment process.

The treatment technique, as it has been described above, is clearly based on classical conditioning, operant conditioning and cognitive factors. Historically, Educational Psychologists, particularly Instructional Psychologists, have been concerned with the manipulation of these same variables to bring about new learning and changes in behavior. When these variables are combined into some new technique to promote the acquisition of math or language skills, or to enable better classroom control in a school setting, they are clearly recognizable as "Instructional" or "Educational" psychology variables. When identical techniques are applied in industrial, or military training settings, they are no less the prerogative of Educational Psychologists even though, to the uninitiated they may appear to be "Industrial Psychology" or even "how I learned to operate the drill press".

In good instruction, the ultimate concern of the teacher must be with the changes which occur in the learner as a result of instruction. In order to ensure good instruction, the teacher must master <u>both</u> the content of his course <u>and</u> the techniques by which he can most effectively

teach it. In the final presentation of a good lesson, however, the course content is almost always more visible to the untrained observer, than are the sophisticated techniques which went into preparing that content. The present study is an investigation of the results of a specific instructional technique, composed of variables drawn squarely from experimental and instructional psychology. The instructional technique, however, is most appropriate to train the specific and highly visible skill of hand warming in the cold.

4. METHOD

4.0.1 Subjects

The experimental subjects were four male and two female volunteers over 18 years old with academic and/or technical backgrounds. All subjects were non-smokers who did not eat or drink one hour prior to each contact. They were screened for a history of relevent medical problems including; vasomotor and cardiovascular disorders, emotional disorders, debilitating stress or anxiety, headaches, physical abnormalities, or current use of medication. No subjects were rejected or replaced. More complete biographic information is provided for each subject in the "Case Studies" section of Chapter V.

4.0.2 Materials

4.0.2.1 Dependent Measure Materials

Manual dexterity was measured with the manual dexterity pegboard from the General Aptitude Test Battery (GATBY). In this test, each of a series of pegs was lifted from its hole in the pegboard, rotated by the thumb and first two or three fingers, and re-inserted into its hole. The object was to turn as many pegs as possible in each of two 30 second trials. The score was the larger number of pegs. The task was performed, timed and scored as described in the GATBY manual (U.S. Department of Labor, 1970 or Testing Division: Canada Manpower, 1972). Administration, however, differed from the manual in two ways. First, each subject was trained

to perform at his optimum level prior to recording the data used in the study. Second, the test was used for both right and left hands.

Finger dexterity was measured with the finger dexterity board from the GATBY adapted for one hand use. In this test the subject used his thumb and index finger to remove a small brass rivet from the board. While holding the rivet he used his second and third fingers to pick up one small brass washer from a stack of washers on a vertical rod. The subject then inserted the rivet through the washer and placed the assembled unit into a hole in the pegboard. The object was to complete as many assemblies as possible in 90 seconds. The score for each hand was the mean of two 90 second trials. Most subjects were given extensive intermittent practice in order to reach a peak of performance.

Hand strength was measured with a Marsh Instrument Company "Jamar" isotonic hand dynamometer. The instrument was calibrated, adjusted for hand size, and used in a standard fashion, as recommended by the manufacturer. Hand strength was taken as the higher reading of two trials.

Tactile sensitivity was measured on the volar pad of each index finger with "Mackworth's V", a hand made tool for the rapid measure of two point discrimination (Mackworth, 1955). Five measurements were made, averaged, and recorded as suggested by Mackworth.

Cold pain was measured with a subjective verbal report

scale from 0 to 100. Zero indicated complete absense of pain. One hundred was the most intense pain the subject had ever experienced .

4.0.2.2 Training Materials

The operant-feedback portion of training used an Autogenic Systems Incorporated (ASI) 1000 b temperature trainer with research grade precision linear thermisters (Yellow Springs Instrument Company). ASI reports that this combination provides an absolute temperature accuracy of approximately 0.27 *F and an absolute temperature resolution of 0.025 *F.

In the classical conditioning component, the hand was flushed with warm water (38 *C) delivered through an insulated hose into the palm of a loose-fitting rubber glove. The water outlet was through holes in the end of each glove digit. The holes were small encugh to restrict the water flow and ensure that the hand was totally surrounded by a layer of warm water. A submersible pump provided nearly instantaneous onset of the water flow with a flow rate of approximately 300 gallons per hour.

In the classical conditioning component finger temperature was monitored with a Model 425 Yellow Springs Instrument with a type 401 thermister probe. The thermister was held in place under the glove with small strips of insulated and waterproof "Diachylon" surgical adhesive tape (Jchnson and Jchnson).

4.0.2.3 Climatic Chamber

All the cold room research was carried out in a 6 by 8 by 7.5 foot "Foster Refrigeration Cold Research Facility" which was maintained at -8 *C. Two large circulating fans continually circulated the air. The wind speed at the surface of the table where the dependent measures were made ranged from 320 to 380 feet/minute with an overall mean of 340 feet/minute (3.86 miles/hour). LeBlanc (1975, page 8) provides a series of curves which permit the calculation of an approximate thermal wind decrement. These curves suggest that the temperature, windspeed, and activity level of the subjects in the present study presented an equivalent stress to that experienced at -14 *C in still air.

4.0.3 Procedure

All research was conducted during the warm summer months to eliminate the effects of changing seasonal and cold weather factors. Each subject contact was conducted at the same time of day to eliminate the effect of diurnal changes in circulatory patterns.

Each subject entered the warm experimental room and was seated. Every effort was made to insure the subject,s comfort and ease. Personal data were obtained and the nature and rationale of the study were explained. The skin temperature of all volar digit pads was recorded. Dexterity measures were introduced and the subject was asked to practice them until no further increase in rate occurred.

The dexterity measures were recorded as described above (shown as Test 1 on the graphics). Hand strength was measured over two dynamometer trials for each hand and the higher reading was recorded for each hand. Tactile sensitivity (volar pad, index finger) was measured five times, averaged, and recorded for each hand (as suggested by Mackworth, 1955). Each subject then donned winter clothing (except gloves) and entered the cold chamber. A thermister was fastened to each index finger (volar pad) and the subject was seated quietly until hand temperature stabilized. All dexterity, strength, and sensitivity measures were repeated and in addition the subject was asked to indicate a subjective measure of discomfort due to hand cold (shown a Test 2 on the graphics). The subject then inserted his dominant index finger into circulated ice water for 5 minutes or until one hunting reaction had occurred or until he felt unable to continue (which ever came first). Finger temperature was recorded every 30 seconds for the length of the ice water immersion. Immediately following immersion the subject was asked to indicate a subjective measure of discomfort (0-100) due to finger immersion.

The subject then received training in the voluntary control of vasodilation of one hand. As described in Chapter III of this thesis the training may be considered in six steps. First, the conditioning components of the experimental procedure were explained to the subject until he could correctly paraphrase both the CS-US relationship

(Baer & Fuhrer, 1970) and the rationale underlying operant vasomotor conditioning (Libo & Femhi, 1977). This step included the subjects selection of a personally meaningful and appropriate thermal image.

Second, the subject entered a cold chamber (-8 *C) with only his face and hands exposed. An effort was made to create an unhurried and relaxed atmosphere throughout the entire procedure. Hand temperature (index finger, volar pad) of one hand was monitored until vasoconstriction was clearly established and stable (no further decreases). Third, the subject was asked to image his warm hand scene as clearly as possible. When the image reached maximum clarity the subject pressed a button and said aloud the sound "WEK".

Within one second after the button press the monitored hand was flooded with warm water until evidence of strong vasodilation was seen (approx. 7 sec.). One to two minutes following the termination of the warm water, the warmed hand was cooled to baseline with a cold water flush and the entire sequence was repeated until the probe trials (11, 21, 30, 40) indicated clear evidence of classically conditioned vasodilation. (The criterion was sufficient vasodilation to allow monitoring for feedback in the subsequent operant conditioning paradigm.) Ten training trials past criterion were provided.

Fifth, a thermister was attached to the index volar pad and visual (zero center meter) and auditory (decreasing tone) thermal feedback was provided to the subject. He was

then asked to raise his hand temperature as much as possible using his classically conditioned thermal response as a starting point. Operant training was continued until a clear and apparently unbreakable plateau was reached. Subjects were encouraged to "play around" with finger temperature throughout training to ensure maximum volitional control. As training progressed the subject was encouraged to move the fingers and perform simple manual dexterity tasks (bend paper clips, tie knots, solve ring puzzles) while simultaneously maintaining high hand temperature. In order to avoid anatomical specificity of training the thermister was moved to other finger pads and the web dorsum as training progressed.

Sixth, the subject was gradually weaned from the feedback until he could reliably produce and inhibit hand warming upon request and without any feedback at all.

Following training of one hand only, the subject entered the cold chamber and was instructed to warm his hands. Hand temperature and all the dependent measures of hand efficiency were obtained for both hands and recorded as before (shown a test 3 on the graphics).

The subject then received feedback training in voluntary vasodilation of the second hand. (Classical conditioning was omitted on the second hand because of complete lateral transfer following the initial training.) Hand efficiency was again measured for both hands in the cold chamber on all the dependent measures except for ice

water immersion pain (Test 4 on the graphics). Finally, the subject was asked to inhibit voluntary warming and all dependnt measures were again performed in the cold (Test 5 on the graphics). (All measures were later re-administered in the warm to insure that no training effect had occurred over the course of repeated testing.)

Following data collection, exit interviews were conducted. Each subject was encouraged to share his unique understanding of the study along with any observations or comments he wished to make. Any seemingly relevent information was recorded.

4.0.4 Design

This study incorporated a combined Multiple Baseline/ABA design to show the relationship between treatment and behavior within individual subjects (for reviews see Craighead, Kazdin, and Mahoney, 1976; Baer, Wolf, & Risley, 1968; Kazdin, 1973).

Figure 4-1 presents a schematic representation of the design for the first, third, and fifth subjects, with hypothetical data to facilitate clarity. For manual dexterity, finger dexterity, and hand strength the ordinate of each graph represents the percent efficiency of hand function in the cold given by cold performance/warm performance times 100. Tactile sensitivity is given by 10-cold performance/10-warm performance times 100. Pain is the subject's rating of his own pain. On this scale 0

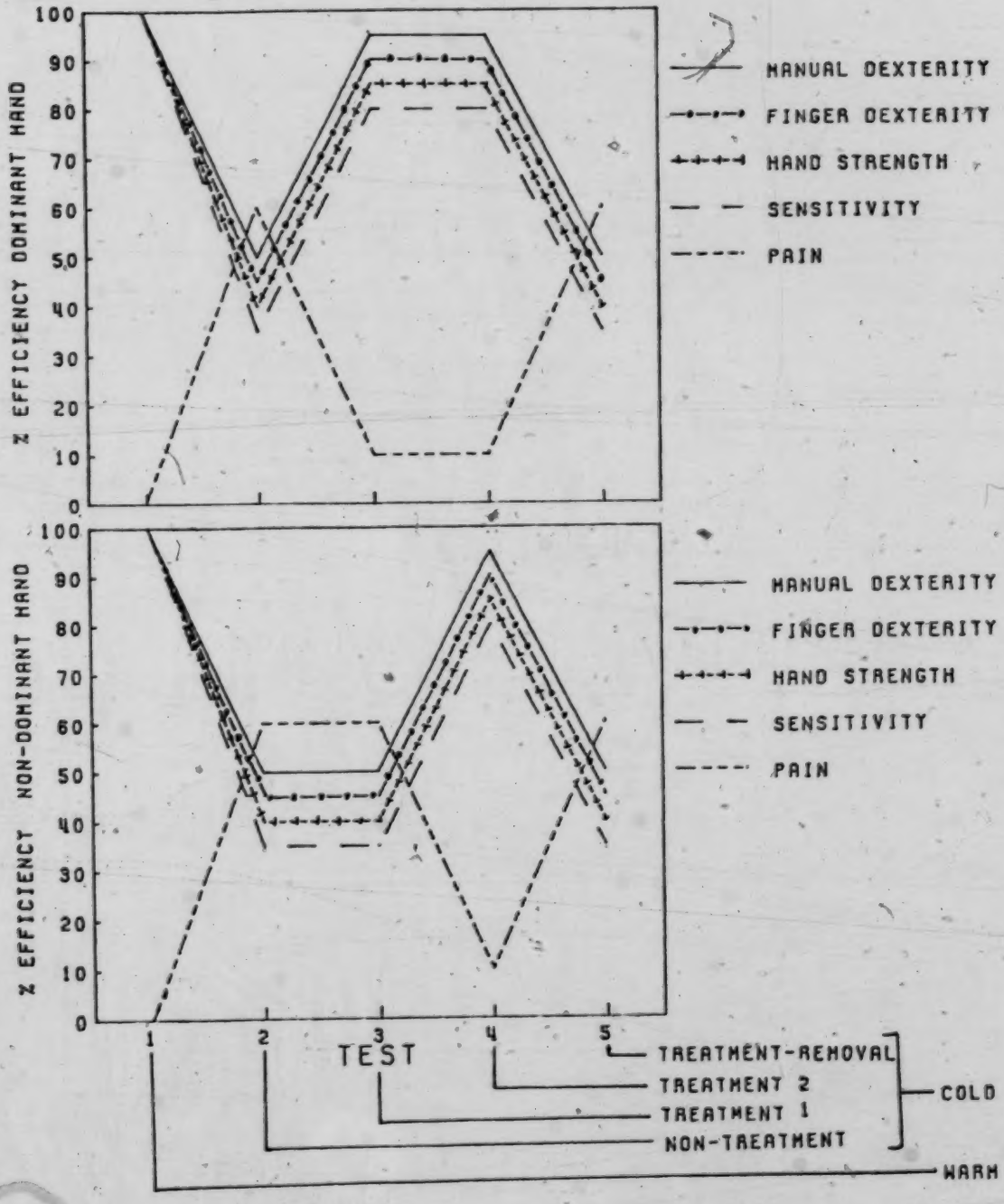


Figure 4-1 Schematic representation of the method for plotting hypothetical results of hand efficiency measures in the combined "multiple baseline/ABA design with single subjects.

indicates no pain and 100 indicates the most severe pain the subject has ever experienced.

Test 1 on the abscisa shows performance in the warm. Tests 2, 3, 4, and 5 show cold-chamber perfcrmance.

The multiple baseline component of the design is given by trials 2, 3, and 4. After baseline (test 2) the dominant hand only was trained. Both hands were then retested in the cold. If the hypotheses presented in the study were correct, an increase of hand efficiency (and hand temperature) should have occured on all dominant hand measures but not on non-dominant hand measures for these subjects. Following test 2, the non-dominant hand was trained and both hands were re-tested in the cold. Again, if the hypotheses were correct, non-dominant hand efficiency and temperature should have increased.

The design was identical for the second, fourth and sixth subjects except that training was done first with the non-dominant hand and second with the dominant hand.

The ABA component of the design is given by tests 2, 4, and 5. (Right and left hand measures can be combined if desired.) From this perspective, test 2 indicates decreased hand efficiency due to cold. Test 4 indicates the probable result of training and the magnitude of the effect. At test 5 the subject was asked to refrain from handwarming while performing the handwarming efficiency tests. That is, the situation remained constant except for the treatment which was removed. If the effect also disappeared then it could be

asserted that the results of the study (trial 4) were due to the experimental treatment. If no treatment effect had been found on tests 3 or 4, test 5 would have become unnecessary because there would be no deviation from the baseline and hence there could be no return to baseline.

The present study was not intended to make a definitive statement concerning the effects of treatment on either ice-water immersion pain or on CIVD. To some extent this ommision represents experimenter reluctance to subject volunteers to numerous and extended painful immersions without suitable compensation and particularly in view of the large amount of time required just for the present study. Never-the-less, sufficient information was gathered to guide a future study of these variables. Immersion pain statements as well as CIVD onset temperature and magnitude were compared from right hand immersions at tests 2 and 3 but neither reversal nor opposite hand measures were made. Pain comparison data (on the scale of 0-100) were collected at the end of both immersion periods. Again, the information gathered may assist in the design and direction of future studies but can not be used here to assert that the treatment had any effect upon either CIVD or immersion pain.

5. RESULTS AND DISCUSSION

5.1 Overview

This chapter begins with the presentation of the combined data and a discussion of general effects relevent to the hypotheses directly under test. A case study analysis is then used to present anomalous and demographic data as well as training information, incidental observations, and pertinent anecdotal reports. A tentative component analysis and a number of theoretical and research issues are discussed next, in terms of the group and single subject data. The chapter closes with a brief summary of the results and conclusions.

5.2 The Combined Data

It should be recalled, prior to the presentation of the combined data, that this study was conceived, designed and executed as a single subject design with replications. At the time of this writing, there is widespread debate within the applied behavior analysis literature on the issue of which statistical analyses are appropriate to single case experimental designs or if indeed statistical analysis can ever be appropriate with single subject designs.

It is not the writers intent to engage in the ongoing debate, therefore the analysis of the combined data below includes summary statements of probability for all measures on all trials. In the vast majority of cases the statistical

probability of the result occuring by chance is less than 0.000001 and in almost all the remaining cases the probability is between 0.000001 and 0.05. In most of these cases a probability statement adds nothing to a visual inspection and a verbal statement of the applied significance. In a few cases however the statistical analysis does function as an aid in decision making. For any given instance the analytical procedure which is most useful in understanding the data is the one which is employed. The nature of the data dictates that, overall, the statistical analysis is the less emphasized approach. Should the reader desire them, complete statistical summary tables are appended (Appendix D) as are the raw data (Appendix E).

5.2.1 The ABA Design Over All Hands

The ABA aspects of the design are considered first in order to permit the assertion that the findings obtained in the study were, in fact, the result of the treatment provided. Where statistical probabilities are reported they reflect the use of a one way analysis of variance for repeated measures to examine the effects of cold, treatment, and treatment removal on each of the dependent measures. Tukey multiple comparisons were computed (Winer, 1971) and the probability is reported in the text as $p <$ or > 0.01 or 0.05.

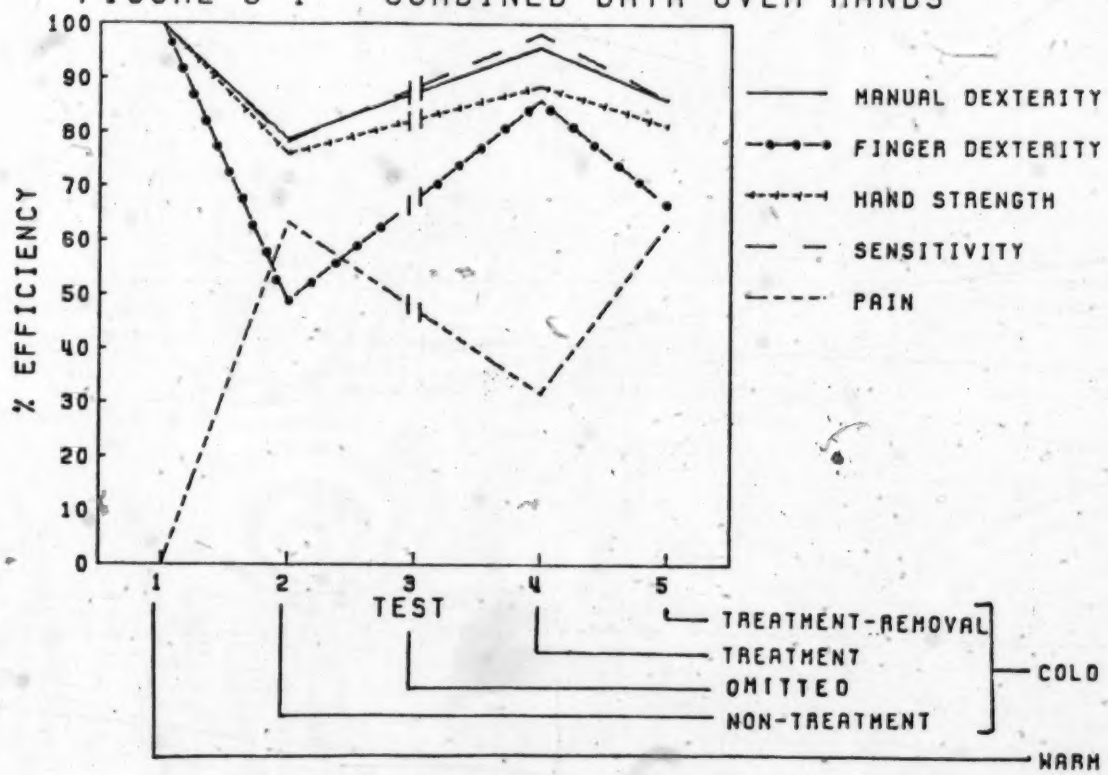
For each dependent measure, the data for test three was removed from the analysis and was not shown on Figure 5-1

because the test is neither a discrete control nor a discrete treatment and thus is only meaningful in the multiple baseline component of the overall design.

The logic of the ABA experimental design should be briefly recalled. After baseline information has been gathered the treatment is introduced. If the target behavior changes one may then suspect that the change occured as a result of the treatment. If the treatment is then withdrawn (test 5) and the behavior reverts to baseline levels one may assert that the treatment was responsible for the change (Craighead, Kazdin, & Mahoney, 1976).

Figure 5-1 presents the dependent measures in percent efficiency over all testing conditions and calculated as reported in chapter IV. On Figure 5-1 test 2 was the non-treatment, or baseline condition. Test 4 was performed following treatment and indicates a substantial improvement in performance on all measures. Test 5 is the treatment withdrawl condition in which the subjects were asked to refrain from voluntary warming while performing the tasks in the cold. Figure 5-1 shows that at trial 5 all dependent measures fell towards the baseline. Pain, however, was the only measure in which this return was complete. For manual dexterity, finger dexterity, and pain the return to baseline was statistically significant ($p<0.01$) but the return was not significant for hand strength and tactile sensitivity ($p>0.01$). The issue raised by this partial return to baseline is whether the writer can assert that the treatment

FIGURE 5-1 COMBINED DATA OVER HANDS



results occured exclusively as a result of the treatment. The issue is resolved by examining the possible reasons for the partial return to baseline.

Two explanations could account for the partial return to baseline. The first is that the subjects failed to inhibit their warming completely so that performance on test five measures declined only to the extent that the treatment was removed. The second interpretation is that some unknown variable occured simultaneously with the experimental treatment to bring about the change found on test 4. From this second perspective the lack of return to baseline on test 5 would reflect the continuing action of the unknown variable. These two possible interpretations are considered in turn.

There is substantial evidence to support the suggestion that treatment was not completely removed on test 5. First, the experimenter observed far more frequent flushing of the hands at test 5 than at test 2 for 5 of the 6 subjects. (This was not seen in the first subject, probably because it was not looked for until the problem became evident from the final data for the first subject). Second, all subjects were asked both at the conclusion of test 5 and at the de-briefing if they had continued to warm in trial 5 in spite of instructions not to warm. All six subjects reported that their hands had indeed warmed. Four of the six subjects (1,2,3,6) reported that they voluntarily induced hand warming "just a little bit" in order to counter the very

aversive cold pain. The other two reported a variant of the theme that they were aware of a recurrent warming "just happening" as their hands became painful.

Third, there is some evidence that the cold laboratory context itself became a discriminated stimulus for hand warming. The de-briefing interview was held in the cold laboratory complex for 4 of the subjects (1,2,3,6) about one week following test 5. Upon entering the room for his exit interview subject 3 commented that "Just comming in here I can feel my hands start to warm up." Subjects 2 and 6 subsequently confirmed experiencing a similar effect. The theoretical explanation for this situation is straightforward if one considers the experimental context to be an avoidance learning situation. In this case, the laboratory setting signified the onset of a painful cold exposure. The volunteers had been taught both to escape and to avoid cold pain by warming their hands. When one considers that the avoidance learning paradigm is extremely powerful it becomes highly predictable that the subjects would perform their avoidance response upon the presentation of the contextual cues.

In summary, three lines of evidence suggest that in the overall ABA data the return to baseline was incomplete because of partial treatment removal. The experimenter observed evidence of handwarming, the subjects reported some handwarming, and one can predict handwarming from a theoretical analysis of the situation. Although this

evidence is strong, it does not rule out the possibility of the co-existence with the treatment of an unknown facilitative variable.

If such a variable was present it could only have functioned within the experimental context. This may be asserted because the subjects were seen in a staggered or sequential fashion over time. That is, if the hypothesized variable was associated with a pervasive event occuring during the course of the experiment (e.g. weather change, season change, amount of sunlight change etc.) it would not have affected any of the early subjects and would have affected all trials of the later subjects. Instead, the effect is found staggered over time so as to occur between the second and fifth trials of each subject. It is unlikely that the hypothesized variable could be associated with changes in individual behaviors (e.g. diet, sleep, exercise, fatigue etc.) because the effect was found on all subjects and then only on the fifth test. It was concluded, therefore, that if an unknown facilitative variable existed it must be a part of the experimental context (e.g. physiological adaptation to the cold due to repeated exposure, decreased fear due to repeated cold exposure, increased motivation in an effort to "do well for Al", etc.). In order to test for the presence of such a variable, a second, co-existent experiment was performed.

5.2.2 Experiment Two: Replicated Single Subject Controls

5.2.2.1 Method

The overall experimental setting and conditions for experiment 2 were identical to experiment 1. The two male subjects were selected and screened as described above for experiment 1. The dependent measure materials, the time spent in the chamber, the seating arrangements, and the testing procedures were the same in both experiments. Only two aspects of the procedure differed. First, both control subjects were told that they were taking part in an experiment to determine the effect of repeated cold exposure on hand efficiency. Second, those periods that would normally have been training periods in the cold were spent discussing neutral topics with the experimenter. The design, data collection, and scoring of the second experiment were identical to the first.

5.2.2.2 Results

Figures 5-2 and 5-3 present the dependent measure means as percent efficiencies for non-treatment subjects 1 and 2 respectively. Note that the results for test 2 on Figure 5-3 have been omitted because the data were confounded when the subject repeatedly warmed his unused hand between his legs each time he leaned forward to the table to perform a dependent measure task. This omisson of data does not affect the results in regard to the identification of a possible hidden variable at later trials.

FIGURE 5-2 CONTROL SUBJECT ONE (DAVID)

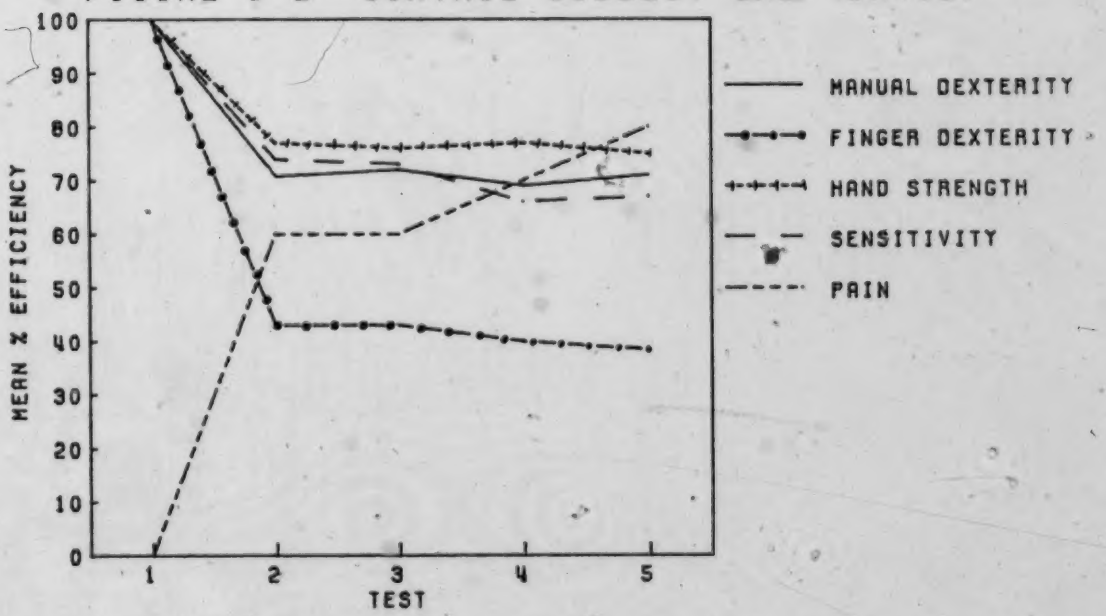
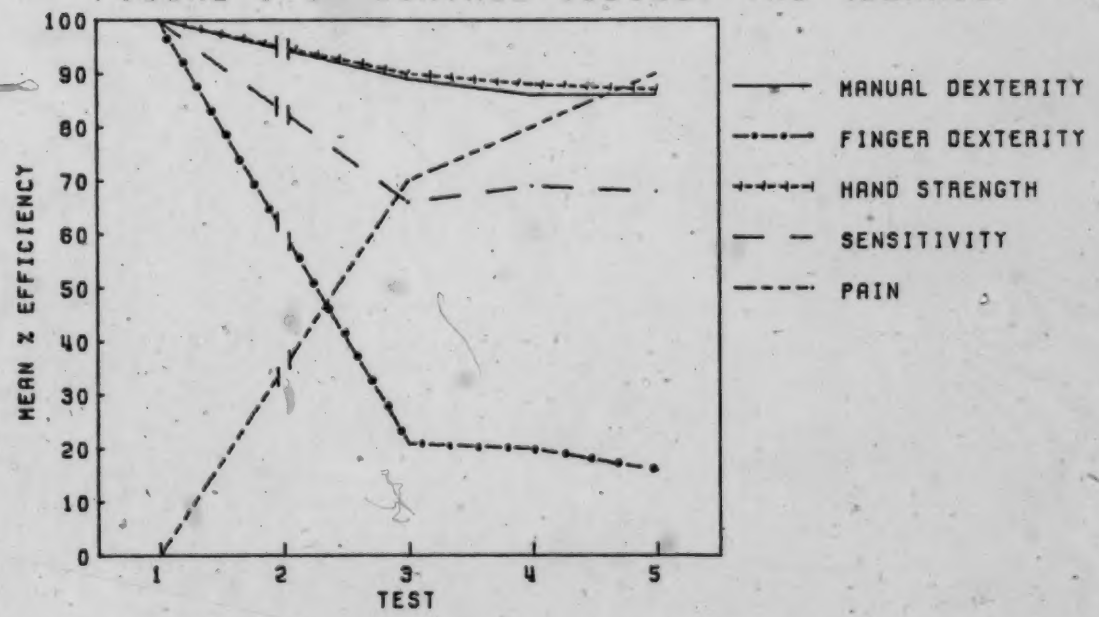


FIGURE 5-3 CONTROL SUBJECT TWO (DENNIS)



Figures 5-2 and 5-3 show that the experimental context alone did not produce any increase in dependent measure performance at any time including the fifth testing period. Both subjects however experienced pain as increasing steadily across tests. The subjective pain increase appears to represent a predictable sensitization to expected and relatively inescapable pain. The pain increase is clearly opposed to the pain decrement between tests 2 and 4 which was reported in the treatment data of Experiment 1. Thus the data are unequivocal with respect to the issue at hand. The experimental context alone did not produce any change in performance that could be construed as facilitative of the voluntary hand warming treatment under investigation in the present thesis.

5.2.2.3 Discussion

From the results of experiment 2 it was concluded that there was no evidence to justify the suggestion that an unknown variable acted to facilitate the voluntary handwarming treatment effect.

5.2.3 The ABA Design Over All Hands: Continued

Recall that two possible reasons were advanced to account for the incomplete return to baseline on test 5. Three lines of evidence have shown that the treatment was only partly removed in test 5 and very likely prevented a complete return to baseline. Experimental evidence has

countered the suggestion that unknown variables were acting in facilitating the treatment effect at test 4. It is therefore asserted that the return to baseline on test 5 is logically equivalent to a complete return to baseline. Hence, in keeping with ABA design logic, it is asserted that the experimental treatment was responsible for the increase in hand efficiency shown between tests 2 and 4 of Figure 5-1.

5.2.4 Testing The Hypotheses

Given that the treatment is held to be responsible for the overall increases in hand efficiency reported in Figure 5-1 it is possible to evaluate 5 of the 6 hypotheses under test.

5.2.4.1 Hypothesis One: Manual Dexterity

Figure 5-1 shows that manual dexterity fell to 78.8% of warm performance upon exposure to the cold ($p<0.01$). Following treatment, manual dexterity improved by 16.9% ($p<0.01$) to 95.7% of warm performance, which is not significantly different ($p>0.05$) from normal. That is, after treatment, hands were as dexterous in the cold as they were in the warm. Hypothesis one is thus clearly supported in that voluntarily warmed hands are substantially more dextrous than unwarmed hands in a standard cold test.

5.2.4.2 Hypothesis Two: Finger Dexterity

Figure 5-1 shows that finger dexterity fell to 48.8% of warm performance upon exposure to the cold ($p<0.01$). Following treatment, finger dexterity improved by 37.1% ($p<0.01$) to 85.9% of warm performance. Hypothesis two is thus clearly supported, in that voluntarily warmed hands are substantially more dextrous than unwarmed hands in a standard cold test.

5.2.4.3 Hypothesis Three: Hand Strength

Figure 5-1 shows that hand strength fell to 76.0% of warm performance upon exposure to the cold ($p<0.01$). Following treatment hand strength increased by 12.5% ($p<0.05$) to 88.5% of warm performance. Hypothesis 3 is thus clearly supported in that voluntarily warmed hands are substantially stronger than unwarmed hands in a standard cold test.

5.2.4.4 Hypothesis Four: Tactile Sensitivity

The tactile sensitivity graphic in Figure 5-1 represents an initial fall in two point discrimination from 1.75 mm to 3.55 mm ($p<0.01$). Following training tactile sensitivity increased so that subjects could identify points only 1.9 mm apart ($p<0.05$) which is not significantly different from warm performance ($p > 0.05$). The same data, given as percentages of change from two point discrimination in the warm are a decrease in sensitivity due to cold of

21.8% and an increase due to training of 20.1%. That is, after treatment, hands were as sensitive in the cold as they were in the warm. Hypothesis 4 is thus clearly supported in that voluntarily warmed hands were substantially more sensitive than unwarmed hands in a standard cold setting.

5.2.4.5 Hypothesis Five: Pain

Figure 5-1 shows a subjective pain rating due to cold of 63.3 out of a possible 100 ($p < 0.01$). Following training, pain ratings fell by 31.6 ($p<0.01$) to 31.7. Hypothesis 5 is thus clearly supported in that voluntarily warmed hands were substantially less painful than unwarmed hands in a standard cold test.

5.2.4.6 Hypothesis Six: Cold Induced Vasodilation

It should be recalled that this study was intended to gather pilot information concerning the effects of treatment on cold induced vasodilation rather than to make a definitive statement. An AB design was used and subjects were allowed to cpt cut of the ice water immersion component if they wished. Complete but highly equivocal data were gathered on 4 of the 6 subjects. Both the nature and the quantity of these data are such that the writer is not justified in considering the sixth hypothesis to have been tested. Therefore, no statement is made here concerning the hypothesis. The CIVD data are presented and discussed below under "Equivccal Findings".

5.2.5 Differential Effects

Figure 5-1 (test 2) shows that exposure to the cold affected each of the dependent measures to a different extent. Similarly, Figure 5-1 shows that treatment had a differential magnitude of effect on each of the measures. In rank order by percent change from the warm performance, the most affected of the performance measures was finger dexterity (51.2%) followed by hand strength (24%) and manual dexterity (21.2%). The differential cold effect may be explained in terms of the anatomical location of the effectors required for the performance of each task. The performance tasks are rank ordered below by the proportion of non-hand muscle activity required for each. The finger dexterity task required much activity by the muscle slips located in the hand with some activity by the forearm effectors. The hand strength task required more gross hand function with little activity by the hand muscle slips and much more work by the forearm muscles. In both the finger dexterity and hand strength tests the more proximal effectors acted only to stabilize the hand and forearm. The manual dexterity task however required not only hand and forearm activity but upper arm, chest, and shoulder activity. Thus, the rank order of tasks by proportion of hand muscle involvement is the same as the rank order by percent change from the normal on exposure to the cold. When one considers that only the hand itself was directly exposed to the cold it seems reasonable to suggest that the

performance tasks were differentially affected by cold because the muscles required to perform them were differentially exposed to the cold.

The performance measures were differentially improved by the treatment in the same rank order (finger dexterity, 51.2%; hand strength, 24%; manual dexterity, 21.2%) as they were improved by the cold. The principle here is identical to the arguement directly above. That is, treatment was focused directly on the hand and not on the more central systems. As a result the tasks requiring proportionally greater hand muscle involvement also received greater benefit from the treatment.

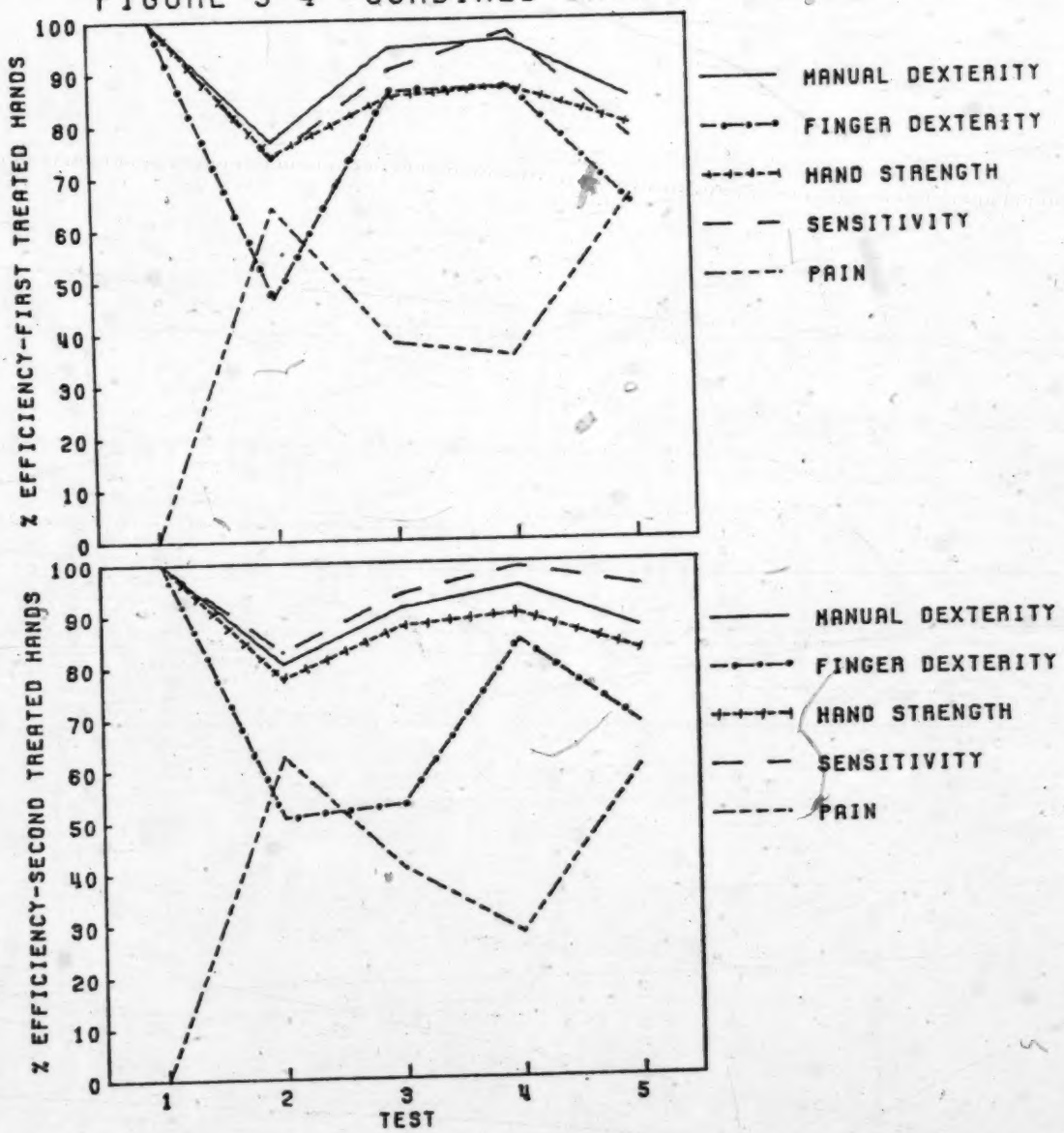
5.2.6 The Multiple Baseline Design Over All Hands

The division of the data into two parts by order of treatment introduction permits the consideration of two further aspects of the study. First, one may examine the degree of spontaneous transfer of training from the treated to the untreated hands. Second, one may determine whether the order of training (and the different training times associated with each hand) influenced the overall magnitude of the treatment effect.

5.2.6.1 Transfer of Training Across Hands

Figure 5-4 presents the combined hands performances for the first-treated-hands in the upper graph and for the second-treated-hands in the lower graph as discussed for

FIGURE 5-4 COMBINED DATA BY TREATED HAND



multiple baseline designs in Chapter IV. All measures were calculated as reported in chapter IV. Training in the upper graph occured between tests 2 and 3. Training in the lower graph occured between tests 3 and 4.

Inspection of Figure 5-4 indicates that exposure to the cold (test 2) produced almost identical performance decrements on both hands for any one measure. It is also apparent that training the first-hands (upper graph between tests 2 and 3) brought about large changes in the predicted directions for all first-hand measures. Of primary interest however is the lesser, but clearly visible, change in the same directions for all measures on the second-treated-hands which occured even though the second-treated-hands had not received direct treatment (i.e. transfer). (Within the second-treated-hands, One way ANOVAS for repeated measures followed by Tukey tests of significance for multiple means found only the change in pain to be statistically significant at the $p<0.05$ level.)

The small but reliable improvement on the untreated hand measures suggests that some minimal transfer of training occured spontaneously between hands. In order to accept this suggestion one must inevitably accept that some central factor (probably neurological) involving both hands was operating at or before the time of test 3. Three findings suggest that the factor was classical conditioning. First, data are presented below ("Single Subject Data") which show clear and complete transfer of the classically

conditioned response between hands. Second, the transferred conditioned response was of very small magnitude and, at the very best could produce only small changes in all measures but pain. (Recall from Chapter II that even miniscule changes in temperature, such as at CIVD onset, frequently produce large decreases in pain.) Third, no clear evidence of spontaneous transfer of biofeedback training was found in any subject . That is, the known transfer of classical conditioning can account for the entire pattern of transfer to the second-treated-hands. Therefore, the transfer of training may be regarded as due to the complete transfer of classical conditioning.

Inspection of Figure 5-4 indicates that training of the second-treated-hands produced continuing improvements on all second treated hand measures. The improvements on tactile sensitivity, manual dexterity, and hand strength were relatively small, but this appears primarily to represent a ceiling effect, in that the three measures were within 12% of warm performance before treatment and could not possibly have risen much more than they did. Neither pain nor finger dexterity was bounded by a ceiling effect and both of these measures improved dramatically after treatment. Ultimately, however, only further research at lower temperatures and accompanied by further reduced hand function could determine the presence of a ceiling effect.

Figure 5-4 shows no pattern that would indicate transfer of training effect between tests 3 and 4.

5.2.6.2 Order Of Training Effects

The mean time required to train the first-treated-hand was approximately 292 minutes (4 hours and 52 minutes) with a range of 185 minutes to 445 minutes and a standard deviation of 88 minutes. These figures include a mean time of 45 minutes for classical conditioning. Classical conditioning was not used in training the second-treated-hands because of apparent complete transfer of training frcm the first-treated-hands (discussed below under "Single Subject Data"). Subjects achieved clear voluntary control of temperature in the second-treated-hands in under 10 minutes (mean=9.5 min; standard deviation=6.1 min) but they were asked to continue practicing to a demonstrated plateau tc insure a strong and reliable effect (mean=49.2 min; range=15 to 90 min; standard deviation=24.8 minutes). That is, subjects trained on the first-treated-hand more than six times as long as they did on the second-treated-hands.

Inspection of the graphed data in Figure 5-4 indicates nc performance differences between first and second-treated-hands on any one measure. The visual inspection was confirmed by a two factor analysis of variance for repeated measures for each dependent measure. Thus it is apparent that the difference in treatment time between first and second treated hands had no effect on the performance measures. This finding appears to be analagous to Taub's (1977) statement that specific training on one

hand location can be transfered quickly, easily and completely to other spots on the same hand. From this perspective, the long initial training time primarily represents time spent in developing appropriate temperature change behavior. Subsequent performance of the warming response at a new site requires only the invocation of an already existing strategy.

5.3 Single Subject Data

The major findings of the present study have been described from the general trends in the group data above. No attempt is made to reiterate the group findings in the single subject reports below. Instead, the case studies present both demographic data which may be useful to future researchers and selected information which is used to address specific issues. Specific issues are discussed following their first occurance in the single subject data. Relevent evidence is then drawn from other subjects as required.

Three issues are described or discussed under the heading "Subject One": Reduced time of hand rewarming following treatment; detramental aspects of hand control due to separate hand training; and the characteristics of the classical conditioning component. Four issues are discussed under the heading "Subject Two": The interaction of pain with the other dependent measures; persistence of voluntary warming during whole-body thermal stress; imagery as a

training component; and the feedback effects of pain reduction following the repeated performance of the classically conditioned response. The effect of personal effort on task performance and the independence of the two parts of the bipartite conditioned stimulus are discussed under "Subject Three". "Subject Four" presents primarily demographic data. The data from subjects Five and Six (female subjects) show that women perform similarly to men.

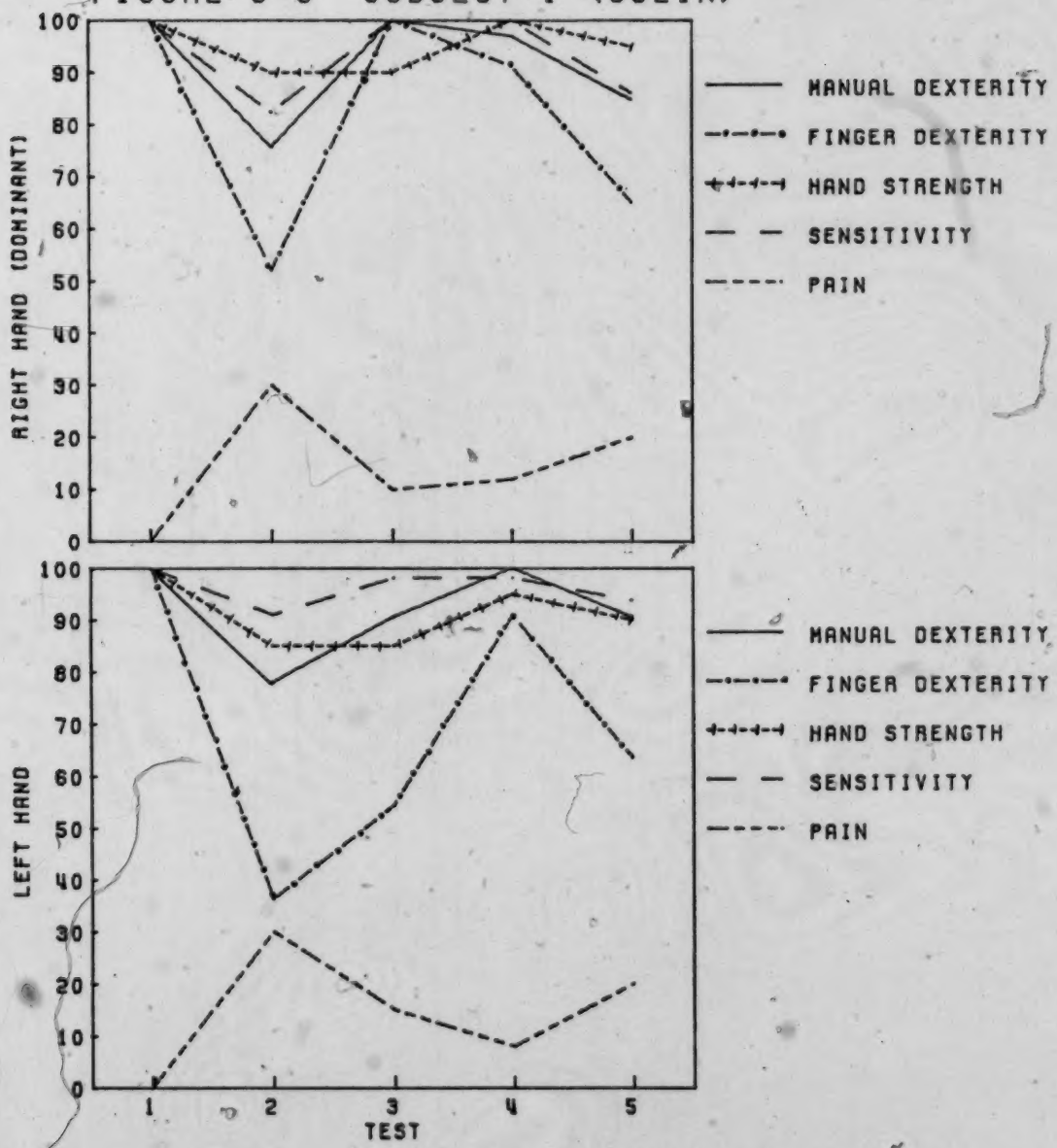
5.3.0.1 Subject One

Figure 5-5 presents the results for Colin, a 32 year old ex-high school athlete who remains relatively physically fit and in good medical health. At the time of the experiment Colin was experiencing substantial personal stress due to the ongoing relocation of his family and business. He was seen over one month, between 9:30 and 12:00 pm with frequent cancellations due to business pressures. He is a graduate of the Northern Alberta Institute Of Technology. After seven years of heavy smoking Colin quit in January of 1978.

Figure 5-5 shows that Colin reported far less pain than average. Colin attributes his low pain rating to having developed "a sense of perspective on pain" following recurrent knee and ankle injuries when playing football as well as painful back injuries sustained in an accident when he was an early adolescent.

Colin reported that, following treatment, his hands

FIGURE 5-5 SUBJECT 1 (COLIN)



rewarmed much more rapidly (approximately 2 min) upon leaving the cold chamber than they had prior to treatment (approximately 10 minutes). Similarly, Colin experienced 2 to 3 hours of a "dull aching pain" after the initial ice-water immersion test but all pain was gone and his finger temperature had returned to normal within 2 minutes of his 2nd ice-water immersion test.

Following test 4 Colin reported that each effort to warm his left hand was accompanied by simultaneous cooling of his right and vice-versa. He retained control of both hands only by shifting his warming strategy back and forth between hands. Colin suggested that the effect was similar to having "one mitten to switch between hands" and that he could probably perform better if he could warm both hands with "one effort".

Much information was gathered from the classical conditioning component of Colin's training. It is discussed here at some length so as to facilitate presentation of similar results in later subjects. In the cold prior to training, Colin did not produce an increase in temperature when asked to image his right hand in a warm place. At each classical conditioning trial past the 4th, however his temperature rose approximately 1/2 Celsius degree in the 4 to 5 seconds prior to the presentation of the unconditioned stimulus. At the first probe trial (trial 11) his finger temperature rose approximately 1/2 Celsius degree, remained there for approximately 20 seconds, and declined. At the

second probe trial (trial 21) his temperature rose approximately 1/2 Celsius degree and remained there for approximately 30 seconds. Classical conditioning was discontinued and the training apparatus was removed. At the experimenters request Colin said "WEK" aloud and his hand temperature increased by approximately 1/2 Celsius degree for approximately 20 seconds. He was then asked to visualize his warm image and his temperature increased by approximately 1/4 Celsius degree. After approximately 40 seconds he opened his eyes and the temperature declined within 2 to 3 seconds. The thermister was transfered to Colins untrained left index volar pad and he was asked to repeat both "WEK" and his thermal image. The thermal results in the untrained hand were identical to the results produced by "WEK" and the thermal image on his trained right hand (i.e. complete transfer of training).

The finding that the temperature increase was smaller for the imaginal conditioned stimulus than for the spoken conditioned stimulus is consistent with the Menzies (1941) and Roessler and Brogden (1943) studies which found that a spoken utterance (WEK) produced a stronger vasomotor response than other types of conditioned stimuli. The writer is unable to explain, with confidence, why the image alone produced a temperature increase of 1/2 Celsius degree when the conditioning apparatus was in place but of only 1/4 Celsius degree when the apparatus was removed. This difference may reflect either the loss of insulation

provided by the water glove or insufficient accuracy of the temperature monitoring and recording.

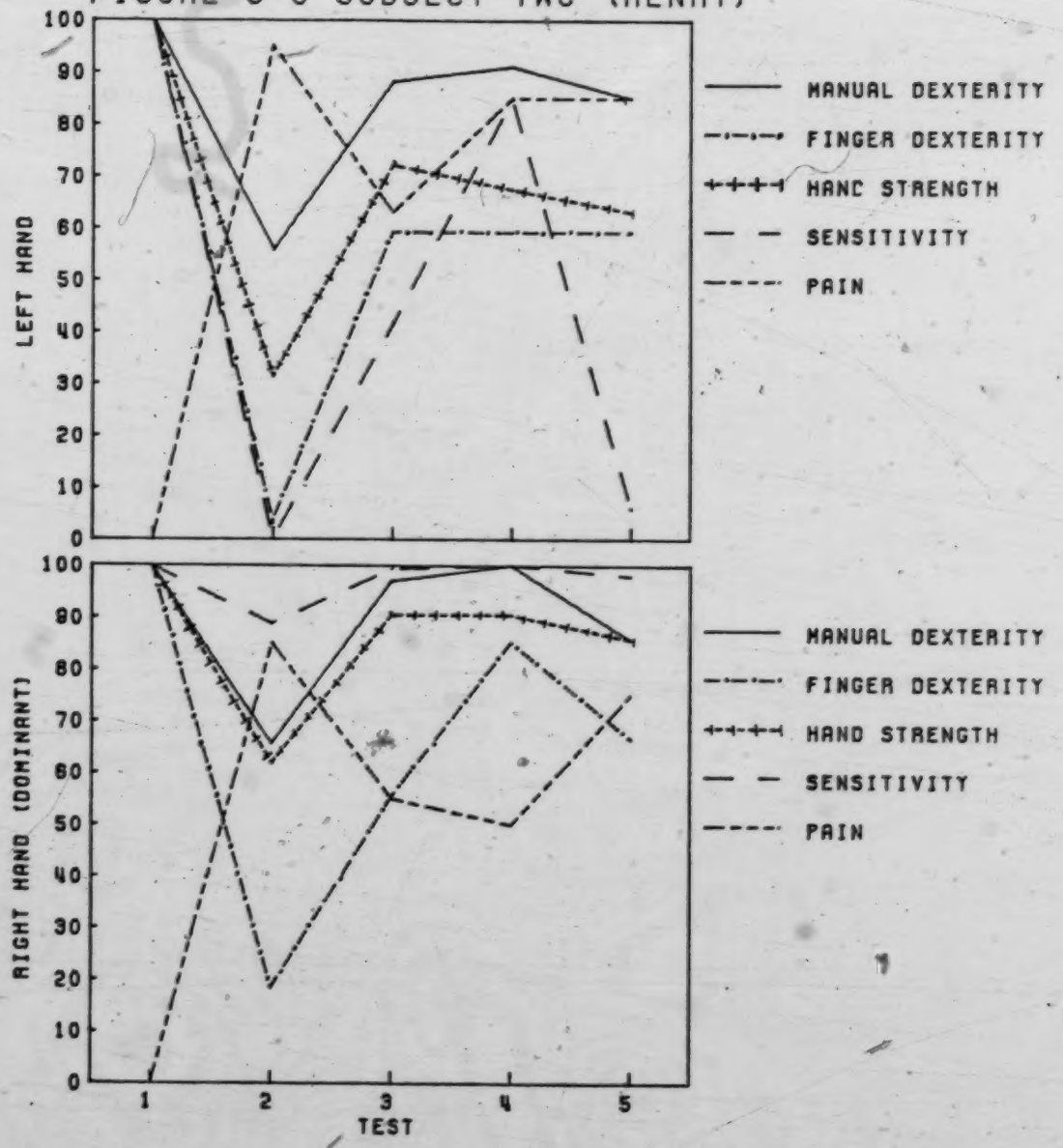
The difference in response persistence between the two conditioned stimuli may represent the fact that "WEK" is a discrete stimulus while the thermal image is continuous. From this perspective, the utterance of "WEK" would elicit a discrete response which typically lasts less than 30 seconds (Shmavonian, 1959). Alternately, the imaged conditioned stimulus is a continuous stimulus which could continue to elicit the response as long as it was presented, which in this case was approximately 40 seconds.

5.3.0.2 Subject Two

Henry is a 32 year old former tennis instructor who stays very fit by playing racket sports three to five times a week. He quit smoking eight years ago after two years of heavy cigarette consumption. Henry has completed two years of general arts courses and has trained himself in guided imagery and meditation techniques over three years.

Figure 5-6 shows that Henry experienced the cold as very painful. Henry attributed his high cold-pain rating to his lack of experience with severe pain in other contexts. There is evidence that severe pain combined with the cold to produce Henry's low scores on the performance measures, particularly hand strength. He reported that he had the strength to pull harder on the hand dynamometer but that his hands hurt too much when he squeezed to allow him to pull

FIGURE 5-6 SUBJECT TWO (HENRY)



his hardest. Henry reported subjectively, that the pain was not a major factor in his low manual dexterity and finger dexterity scores because squeezing was not so major a component of those tasks. Subsequent questioning determined that no other subject consciously experienced a direct pain-vs-performace effect similar to Henry's.

Henry's pain to hand-strength interaction should not be considered as a limitation of his hand-strength data. Henry is different from other subjects on the hand strength task in that his performance ceiling was imposed indirectly by the action of the cold upon his relatively delicate pain perception system rather than by direct action upon his more robust effector system. That the mechanism imposing a ceiling on his hand strength was different for Henry than for other subjects does not alter the fact that his performance was a realistic appraisal of his ability in the cold.

Figure 5-6 shows that Henry's left hand tactile sensitivity fell to zero (complete numbness) at test 2 and nearly to zero at test 5. His extreme reactivity appears to have resulted from rapid cold transfer through minor scar tissue in his left index finger tip. Henry reported that merely begining voluntary warming in the cold replaced the overall numbness in this finger tip with dull and then normal sensation.

On tests 2 and 3 Henry reported feeling his body begin to shiver markedly after approximately 40 minutes of

exposure. On both occasions he suddenly lcst the ability to maintain voluntary hand warming and his hands cooled quickly and painfully. Shivering stopped shortly afterward. His ability to warm his hand voluntarily returned within 5 minutes of stepping out of the cold chamber. He subsequently reported that he was able to rewarm his hands in the warm much more quickly and with less pain than prior to treatment. Subject six (Linda) also lost the ability to warm after 35 to 40 minutes of exposure, just as her body began to feel unccmfortablely chilly. Her control returned within 10 minutes of leaving the chamber.

For both subjects it appears that voluntary warming was overridden by organismic thermoregulatory mechanisms following the onset of organismic thermal stress. Unfortunately, without an accurate monitoring of core temperature it is not possible to make that assertion with confidence. Further, subject 5 maintained hand warming even during body shivering. The relationship between body thermal state and voluntary hand warming is discussed below under "Handwarming And Body Thermal State".

Henry was the only subject to produce an increase in hand temperature pricr to training by imaging his hand in a warm place. He repeatedly produced and maintained increases of approximately 1/4 to 1/2 degree Celsius cn both hands for up to several minutes. After classical conditioning of the left hand, uttering "WEK" produced approximately 1/2 degree Celsius changes lasting 20 to 40 seconds cn both hands. The

left hand then received biofeedback training. Immediately following test 3 the left hand was 3.5 celsius degrees warmer than the right. It was discovered that the left hand did not appear tc respond with further temperature increases either to "WEK" or to the thermal image. The right hand however produced temperature increases of approximately 3/4 of a celsius degree and lasting approximately 45 to 50 seconds.

It is apparent that the conditioned response on the right hand became more powerful between tests 2 and 3 even though that hand did not receive direct training. Unfortunately, from the existing data it is nct possible to determine if the right hand conditioned response was more powerful because of transfer of biofeedback training or because of the negatively reinforcing effects of the pain reduction which accompanied emmision of the response. An experimental resclution of this dichotomy could prove useful because if pain cessation alone was sufficient to reinforce the expansicn of the classically conditioned response then one could produce voluntary hand warming using the rapid feedback from the body's own pain sensing mechanisms and without expensive biofeedback equipment.

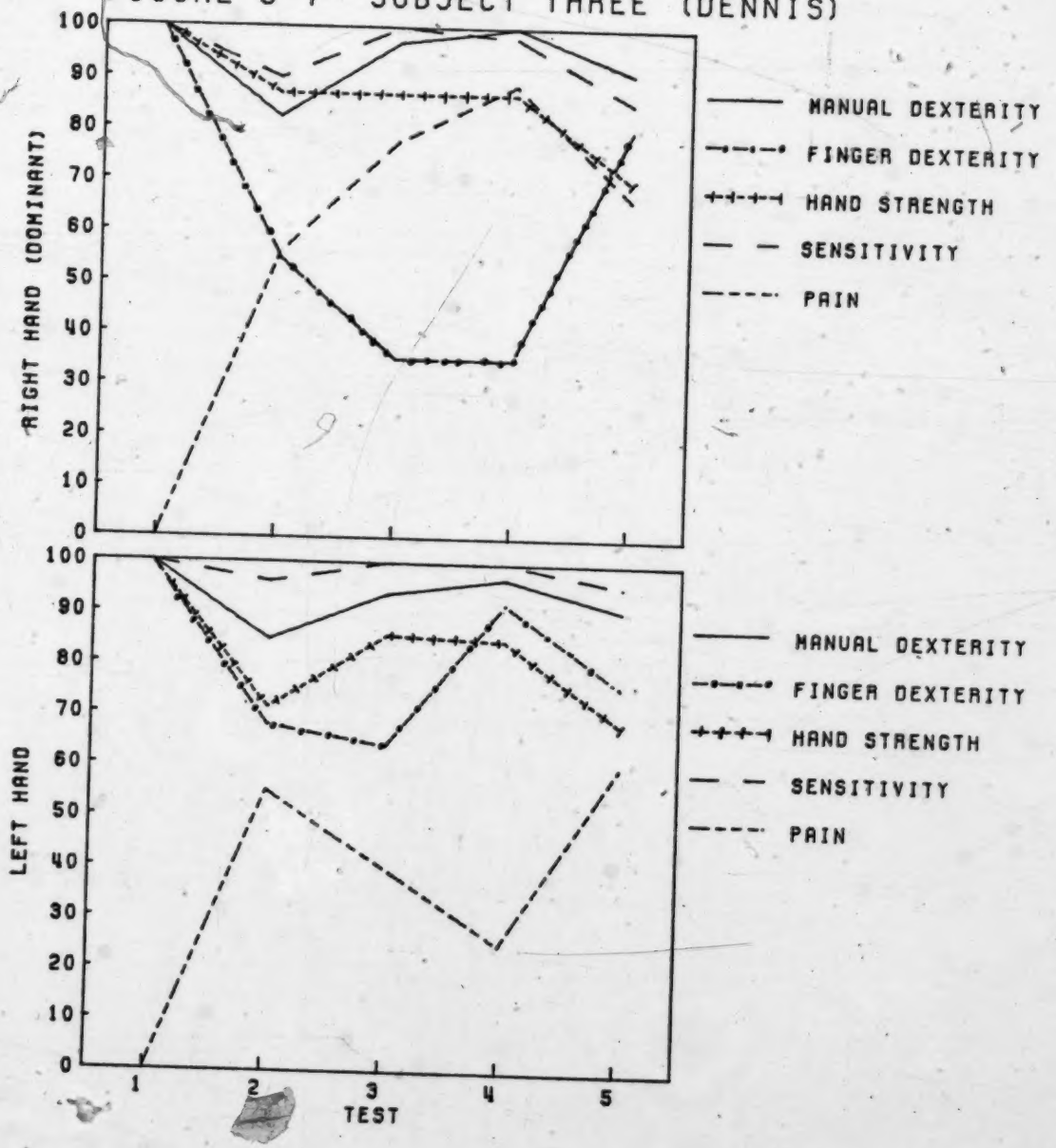
5.3.0.3 Subject Three

Dennis is a very fit 29 year old graduate student. In addition to growing up on a farm he has had several years of outdoor winter laboring and factory experience.

Figure 5-7 shows that Dennis' right (dominant) hand strength declined very little as a result of the cold and did not improve following treatment. Very similar hand strength results were obtained on both hands by subject 4 (Figure 5-8) and on the dominant hand of subject 1 (Figure 5-5). It is likely that this unexpected hand strength behavior is a joint result of the nature of the hand strength task and the work background of all three subjects.

Hand strength is the most responsive dependent measure tc outright effort. Coordination of movement is not required, and the major muscles involved are largely isolated from the cold. If a subject was taught to ignore the effect of ccld on fine movement and sensation, there is little anatcmical reason for a large decline in hand strength performance due to cold. Subjects 1, 3, and 4 have in common a backgrcund of relatively extensive employment as physical laborors. In addition, 1 and 4 have done extensive weight training. It is well known that laborors learn to use their hands (particularly dominant hands) to perform gross motor functions such as hammering, shoveling , lifting, carrying, and prying. Performance of such tasks requires learning to ignore fine or routinely painful sensation initially while the hands toughen up and then later when working for extended periods. It is the writers contention that these three subjects had learned, as laborors, to perform feats of hand strength by simple all out effort while ignoring sensation and dexterity factors. From this

FIGURE 5-7 SUBJECT THREE (DENNIS)



perspective, the very small performance decrement at test 2 for these subjects represents the effect of increased effort made possible by prior experience with sustained hand strength tasks in adverse conditions.

Prior tc the onset of classical conditioning Dennis reported that he is a very poor visualizer. Even after sustained effort he was unable to obtain a clear thermal image. Classical conditioning proceded based primarily on the syllable "WEK". At trials 11 and 21 (the probe trials) a slight increase in temperature occured (too small for an accurate reading). Conditioning was discontinued and the conditioning apparatus removed. "WEK" was found to produce very tiny increases in temperature on both hands. Attempted imagery had no thermal effect on either hand.

In the subsequent biofeedback training Dennis reported that he was able to use "WEK" as an effective aid to training and he achieved excellent voluntary control. Immediately after test 3, Dennis' uttering of "WEK" did not produce a noticeable thermal effect in either hand although his trained hand was 5.5 Celsius degrees warmer than at test 2 and his untrained hand was 3.5 degrees warmer. Dennis was the only subject to exhibit what could be interpreted as evidence of spontaneous transfer of biofeedback training. If the increase in the second-treated-hand temperature was indeed biofeedback transfer then it would be interesting to speculate that the transfer occured because of a verbal rather than a visual training strategy. Unfortunately, one

temperature change at one test for one subject is not sufficient evidence to justify pursuit of this possible explanation.

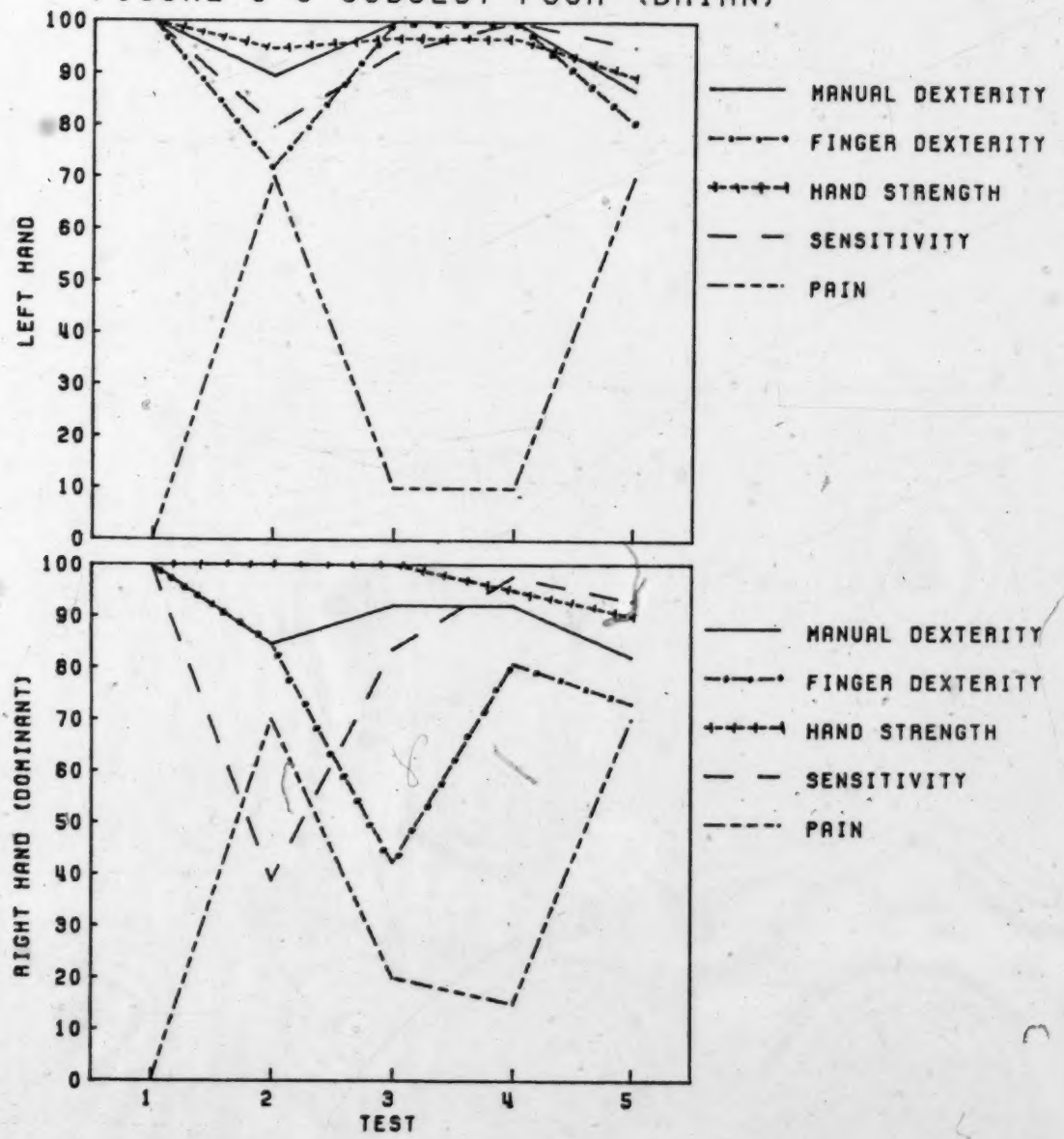
5.3.0.4 Subject Four

Brian is a very physically fit, 34 year old physical education teacher. He is a former competitive swimmer and olympic level wrestler who has remained fit through regular running, weight lifting, and rugby competition. He has never smoked and does not consume stimulants such as tea or coffee.

Brian experienced difficulty in attempting to quantify the pain he experienced. He explained that in his competitive training he has learned to ignore pain or simply to be aware of its presence or absence. Further, he has learned not to dwell on, compare, or quantify pain. Brian suggested that he could rate the "intensity of the cold sensation" accurately but that this might not correspond to pain in a one-to-one fashion. Brian's "intensity of cold sensation" data was compared to the overall pain data and qualitativly similar curves were found. His "sensation" data was subsequently included as pain data.

Figure 5-8 shows that tactile sensitivity on Brian's right hand decreased much more than on his left hand at test 2. Neither Brian nor the writer was able to offer a reasonable explanation for the difference. The very small decrease in hand strength shown in Figure 5-8 at test 2 has

FIGURE 5-8 SUBJECT FOUR (BRIAN)



been discussed above. No other facets of Figure 5-8 appear to require comment.

The classical conditioning component of Brians's training was qualitatively identical to Colin's, which has been presented above. In overview, evidence of classical conditioning was seen by trial 7. Complete left to right hand transfer was found, and the thermal response was larger to "WEK" than to the thermal image. The conditioned response was a temperature increase of between 1/4 and 1/2 Celsius degree which lasted approximately 25 seconds to "WEK" and longer following the thermal image.

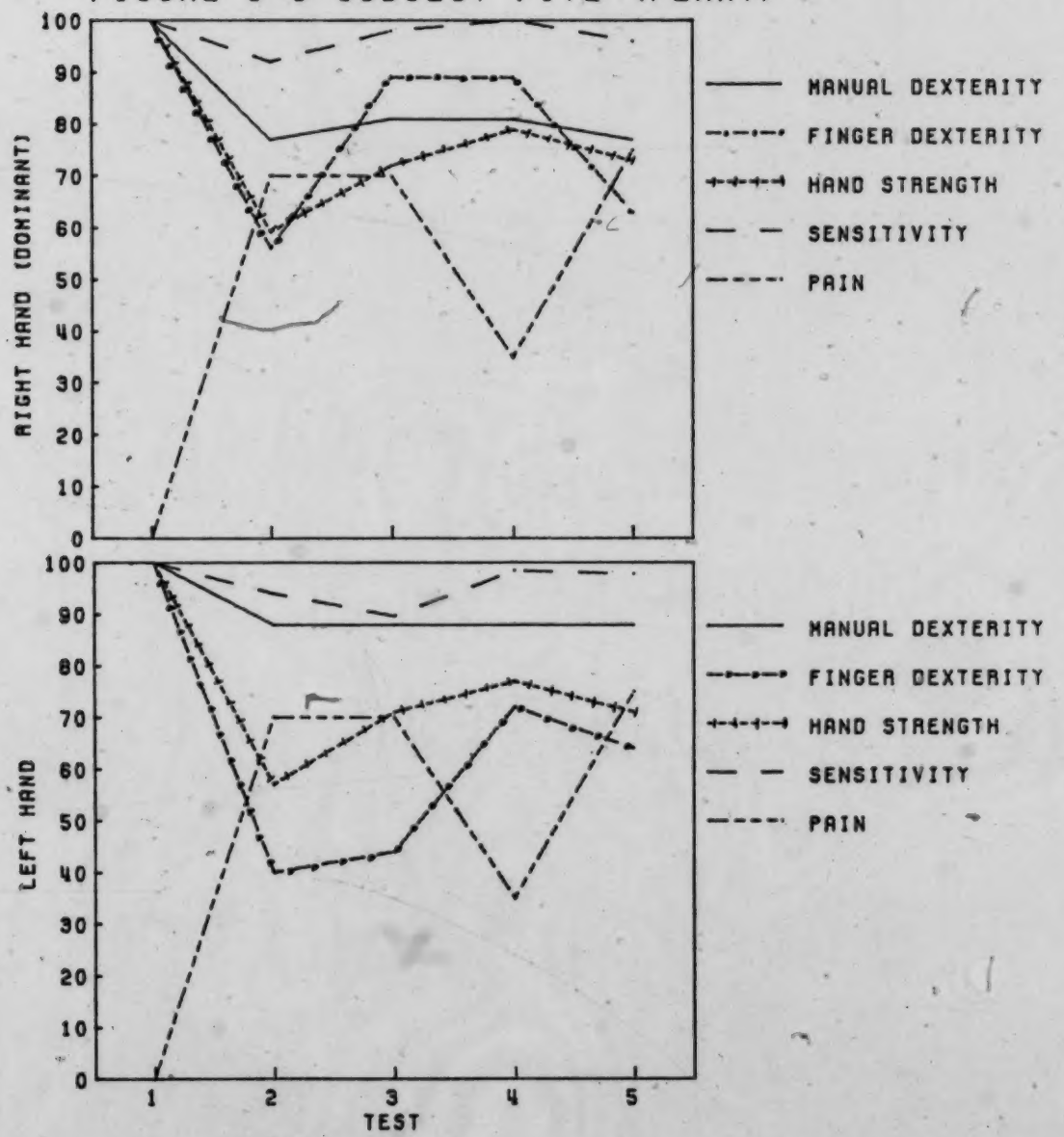
Brian reported that continued voluntary vasodilation upon leaving the cold produced rewarming within 2 to 3 minutes whereas rewarming had previously required 8 to 10 minutes. In addition, following treatment, his hands retained their flexability throughout the rewarming period whereas prior to treatment he had experienced 5 or 6 minutes of subjective joint "tightness" during rewarming.

5.3.0.5 Subject Five

Penny is a healthy 34 year old university student. She stays physically fit by running three times a week and doing yoga exercises daily. She is a lifetime non-smoker.

Figure 5-9 shows that treatment and treatment removal had little or no effect on Penny's manual dexterity for either hand. This is particularly suprizing when one considers that Penny's other performance measures were more

FIGURE 5-9 SUBJECT FIVE (PENNY)



responsive than average to cold, treatment, and treatment removal. Neither a careful inspection of the data nor detailed prcbing at the de-briefing offered any likely explanaticn for the unusual manual dexterity effect.

Figure 5-9 shows no decrease in pain on the first-treated hand at test 3 but pain did decrease normally on both hands following training of the second-treated hand. This appears to be yet another example of the highly idiosyncratic nature of the pain measure. In all other respects, Penny's performance on the dependent measures was qualitatively similar to the overall results reported on Figure 5-4.

Approximately 40 minutes into test 3 and 30 minutes into test 4 Penny began to shiver in her arms, shoulders and upper body with 1 1/2 to 2 inch tremors in both hands. She reported feeling chilled and exposure was terminated within 5 minutes. No similar shivering episodes occured at tests 2 or 5. It seems reasonable to suggest that the shivering was precipitated by excessive body heat loss due to the voluntary handwarming. It is important to note that Penny maintained her voluntary hand warming for the 5 minutes between the onset of shivering and the termination of cold exposure. Even though Penny was the only subject who appeared voluntarily to overide organismic thermoregulatory mechanisms, it is clear that a potential danger exists should handwarming techniques be used in cold settings without further research. The issue of the safety of

voluntary handwarming at cold temperatures is discussed below under" Implications for Further Research".

The classical conditioning component of Penny's training was very similar to Colins (subject 1) which has been presented at length above. In overview, evidence of classical conditioning was seen by trial 6. Complete right to left transfer was found, and the thermal effect was slightly larger for "WEK" than for the thermal image. No new information can be gained by a detailed consideration of Penny's classical conditioning.

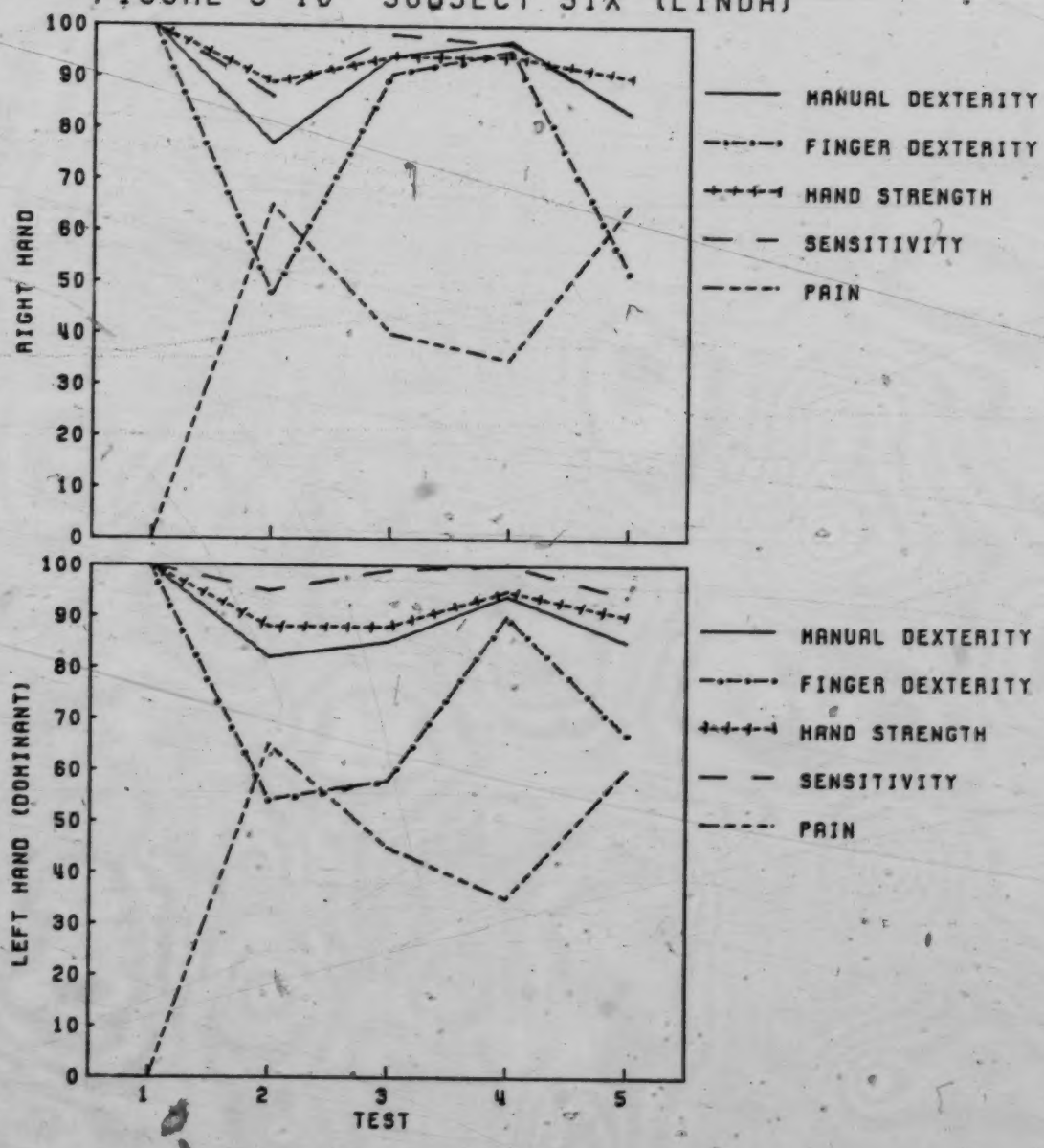
5.3.0.6 Subject Six

Linda is a 22 year old woman who has recently separated from her husband. At 5 feet 4 inches tall and 155 pounds she is approximately 30 pounds overweight. She reports that for regular exercise she tries to go for walks (once around the block) at least once or twice a week. Linda considers herself to be in "pretty good shape".

Inspection of Figure 5-10 shows that her performance on all tasks was consistent with the group data. No additional information can be gained from an individual analysis of her dependent measure performances, but the data of Figure 5-10 should be considered as a clear replication of the single subject design. Linda's inability to maintain voluntary hand warming during thermal stress has been discussed above.

Linda's hands remained "stiff, tingly, and uncomfortable" for approximately 25 minutes after emerging

FIGURE 5-10 SUBJECT SIX (LINDA)



from her first and second cold exposures. Approximately 10 minutes after test 4 Linda stopped shivering and regained control of her handwarming. Within 2 minutes of begining voluntary warming her hand temperature and the subjective sensations in both her hands returned to normal.

5.4 Related Issues

5.4.1 A Tentative Component Analysis

A standard component analysis is performed by sequentially introducing the components of a treatment and monitoring the effect of each on the dependent measures. That procedure is meaningful for components which act independently to affect the dependent measures. It is not meaningful for components which act to enable the performance of subsequent components but do not, themselves, affect the dependent measures. This study contains components of the second variety. The most meaningful analysis in a study which contains enabling components is to examine each component to determine its efficacy in fulfilling the requirements of its particular role within the overall treatment. The present study contains specific combinations of cognition, classical conditioning, and operant conditioning. These combinations are examined in turn below to determine the efficicacy of their performance in enabling the success of the overall treatment.

5.4.1.1 Cognition And Classical Conditioning

Recall from Chapter III that western studies have shown a subjects understanding of the conditioning paradigm to be a necessary component in the classical conditioning of vasomotor activity. In the present study conditioning was not begun until the volunteer correctly explained the classical conditioning paradigm in terms of his expectations for the study. Evidence of clear and rapid classical conditioning was obtained for every subject. Thus, it appears reasonable from the western perspective to suggest that the procedure of insuring subject understanding of the classical conditioning paradigm prior to training (as outlined under "Method" above) was successful.

The same suggestion would be unjustified from the Russian perspective. Recall from Chapter III that the Russians have demonstrated effective vasomotor conditioning without even the subjects awareness of the conditioned stimulus by using interoceptive and intero-exteroceptive conditioned stimuli. In the present study 1/2 of the bipartite conditioned stimulus was interoceptive (thermal image) and 1/2 was intero-exteroceptive ("WEK"). From the Russian perspective classical conditioning would have occured in the present study, whether or not the subjects understood the paradigm.

The present data can not be interpreted to address the issue of the necessity for cognition within the classical conditioning component. Credible investigation of the issue

must await the acquisition of quite different monitoring and recording equipment than that used in the present study.

5.4.1.2 Classical Conditioning

Clear evidence of classical conditioning was obtained with every subject. Further, all subjects except Dennis reported using the thermal image from the classical conditioning component in the initial biofeedback training until they replaced the image with more powerful idiosyncratic strategies. The preference for the imaginal conditioned stimulus reflects a general consensus that visualizing the image allowed more easily sustained and less disrupted warming than the speaking of "WEK" two or three times every minute. (Dennis, who couldn't obtain an image, prefered to rehearse "WEK" covertly until he discovered a better strategy.) Only subject one (Colin) used "WEK" overtly more than a few times and then only for plateau breaking.

Classical conditioning produced one unexpected, and rather startling, side effect. The rubber glove used in conditioning subjects 1, 2, and 3 had its most proximal water outlet approximately 3/4 of the way up the back of the hand. As a result, the unconditioned stimulus (warm water) never reached the wrists of these four people. It was accidentally discovered after the conclusion of the experiment that for all three people, voluntary warming extended only as far up the hand as the upper water outlet

had been during classical conditioning. In the cold each of these people displayed a pink, obviously warm hand with a narrow, cold, white band extending from the upper part of the hand to the cuff of the parka. There was no similar band on the contralateral hands (i.e. warming extended to the wrist).

Although this observation has wideranging potential implications, the writer is unable to justify any one of a number of speculative explanations with the minimal evidence available. This observation, in concert with Taub's anatomic specificity of training and the failure of others to find such specificity, suggests a clearly defined area for further research in which one might expect to find information about the relationship of operant and classical conditioning.

Neither the theoretical basis for including classical conditioning in the treatment, nor the fact that subjects used it, can be interpreted as suggesting that classical conditioning is necessary for obtaining the dependent measure results of the present study. To the contrary, Taub (1977) has reported voluntary warming in the cold by 3 subjects who recieved only conventional biofeedback training (and warming alone is the key factor in hand efficiency). Never-the-less, there is evidence indicating that classical conditioning may be a powerful factor. Consider that in the present study every volunteer was trained rapidly and without difficulty. In most other studies, only selected

subjects have been used because unsuccessful regulators were rejected. Further, in the present study a much larger thermal effect was found (see below) than in most reported studies. Finally, all subjects reported their belief that classical conditioning made the learning of biofeedback control much more rapid than if they had not been conditioned. Typical remarks were of the variety, "I could already do it and biofeedback just let me do it better." Ultimately, the need for a classical conditioning component in cold weather training will only be resolved by specific emperical investigation.

5.4.1.3 Operant Conditioning

Of the three components, operant conditioning appears to be almost entirely responsible for the large magnitude changes in hand temperature following training. Mean hand temperature at the conclusion of test 4 was 12.4 *C (standard deviation = 3.6), or 7.35 C* warmer than at the end of test 2 (5.04 *C, standard deviation = 1.64). In turn, the large performance improvements in the dependent measures are almost certainly due to the increased hand temperature. (The very small dependent measure changes due to classical conditioning were discussed above under "Transfer of Training Across Hands".) Thus, it is reasonable to assert that operant conditioning was almost entirely responsible for the large performance improvements in the dependent measures.

Extended analysis of operant conditioning as an isolated treatment component does not further understanding past that presented from the literature in Chapter III. Operant conditioning was applied in a standard fashion, using conventional equipment, and produced the predicted results. Nothing unusual or unexpected was observed. Questions designed to examine the relationship between cognition and operant training provided highly idiocyncratic case study reports reminiscent of the Libo and Pemhi (1977) findings presented under "Cognition and Feedback" in Chapter III. The only cognitive commonality reported by subjects was the inital use of the classically conditioned thermal image, and/or an image of the classical conditioning glove.

5.4.2 Equivocal Findings

5.4.2.1 Hypothesis Six: Cold Induced Vasodilation

In the present study, 4 of the 6 subjects completed the comparison CIVD tests. Figure 5-11 shows that treatment had no apparent effect on finger cooling patterns for subject one. Figure 5-12 shows that for the second subject the treated finger was almost 10 Farenheit degrees cooler than the untreated finger after 1/2 minute of immersion but the difference disappeared within 4 minutes. Figures 5-13 and 5-14 show that for the third and fourth subjects the treated fingers were initially approximately 10 Farenheit degrees warmer than the same fingers prior to treatment but the difference disappeared within 3.5 minutes. These results can

FIGURE 5-11 FINGER TEMP IN ICE WATER (COLIN)

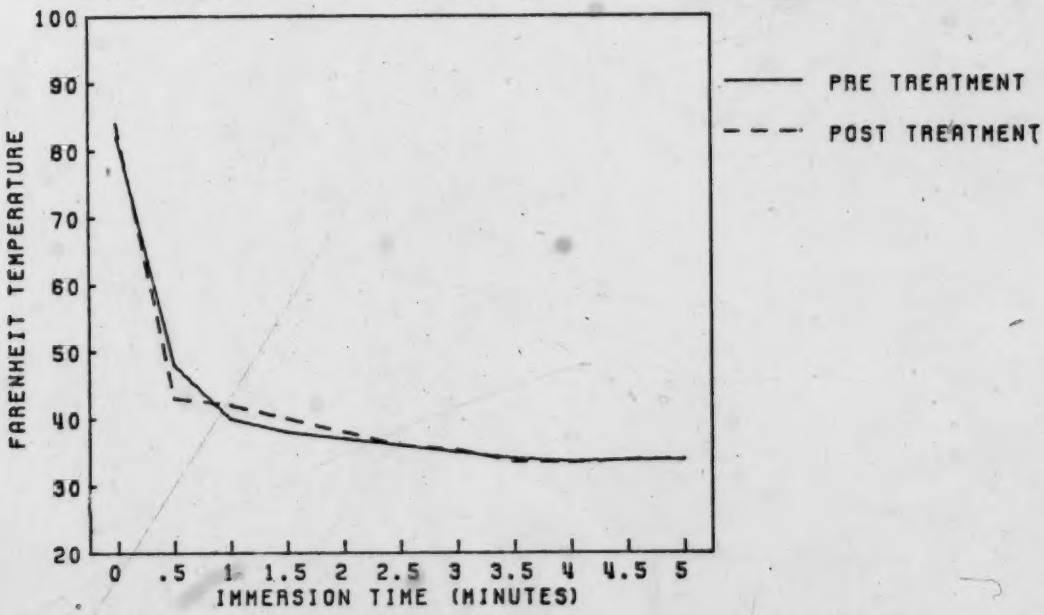


FIGURE 5-12 FINGER TEMP IN ICE WATER (HENRY)

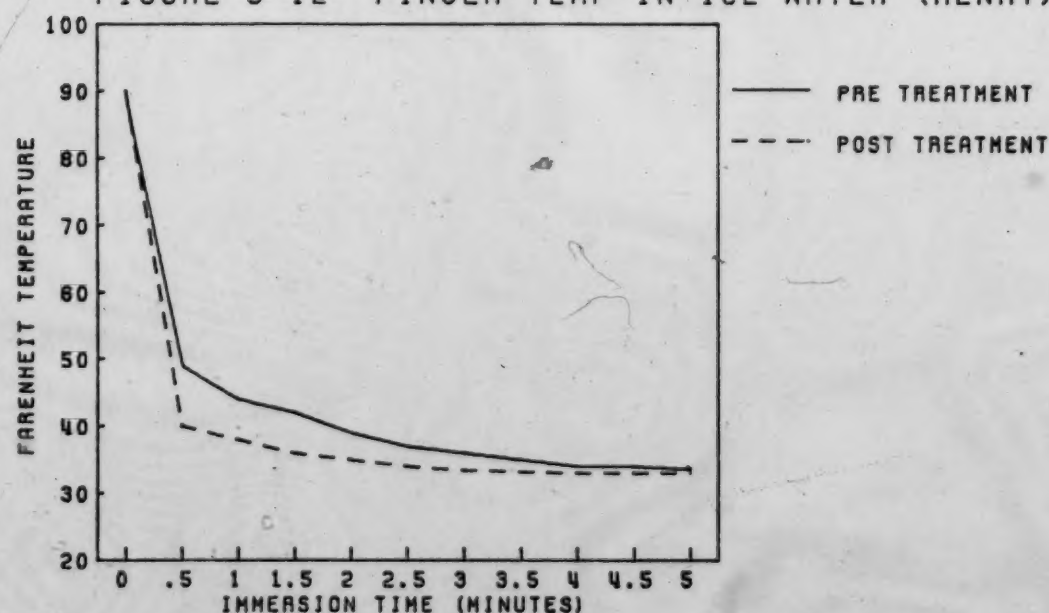


FIGURE 5-13 FINGER TEMP IN ICE WATER (DENNIS)

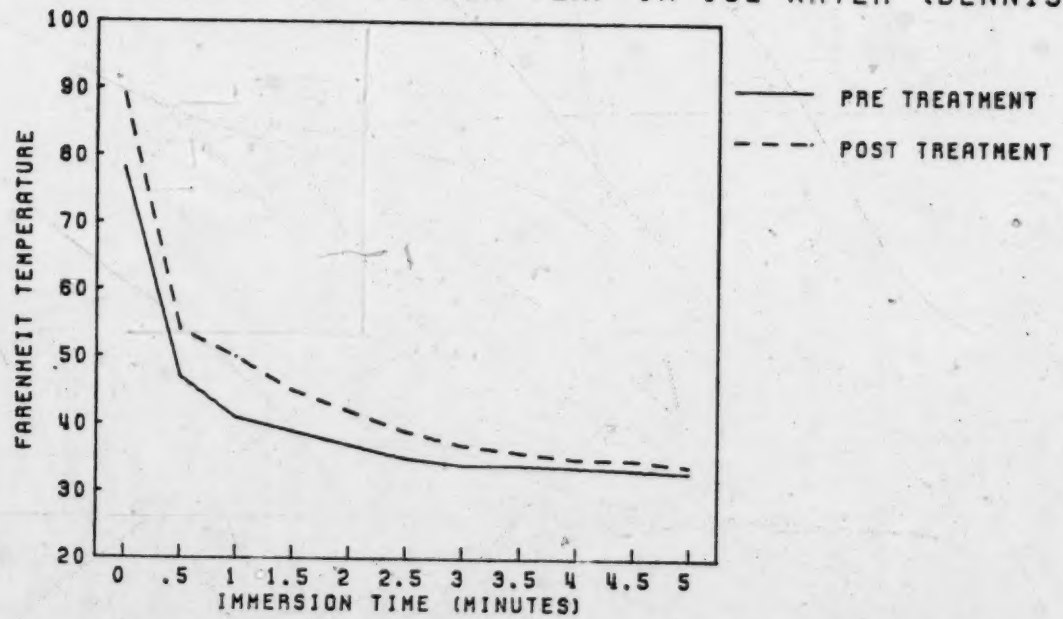
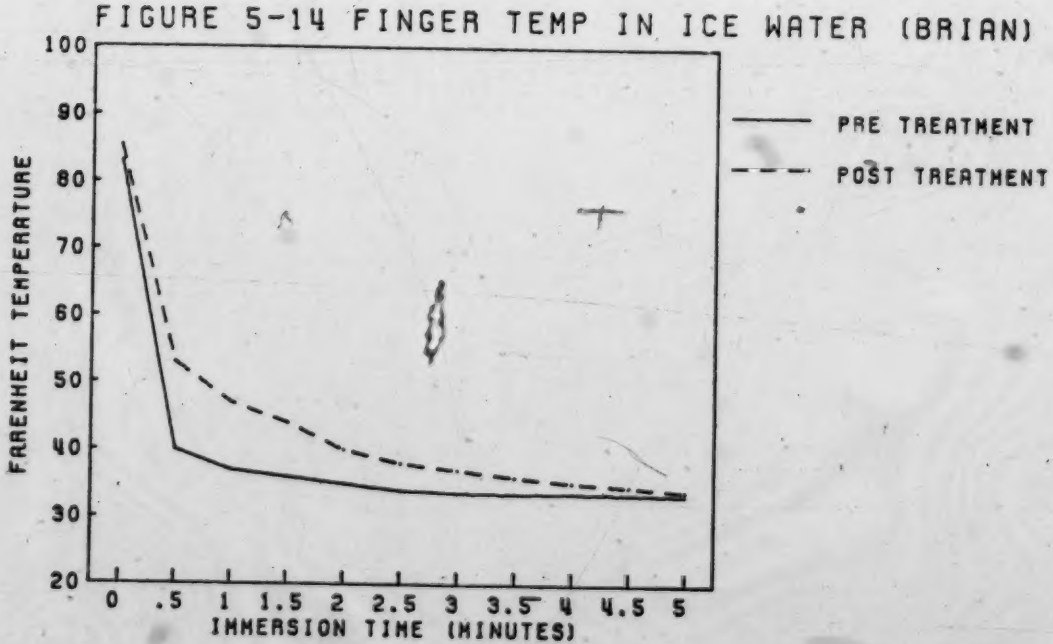


FIGURE 5-14 FINGER TEMP IN ICE WATER (BRIAN)



only be considered equivocal.

Recall from Chapter III that Taub (1977) trained three subjects to maintain handwarming in the cold. Of these, one subject exhibited a 9 Fahrenheit degree earlier onset of CIVD. Results with his second subject were equivocal and the third subject did not participate in the study.

When Taub's findings are added to the present findings it seems reasonable to suggest that little will be gained by further incidental research into the relationship of CIVD and voluntary handwarming.

5.4.2.2 Handwarming And Body Thermal State

Recall from Chapter III that Taub (1977) trained three subjects to perform voluntary handwarming at 55*F (+12.8*C) even though they were lightly dressed. His subjects continued to self regulate even though they were interrupted by violent shivering. Taub's finding was the first published evidence that voluntary handwarming was capable of overriding organismic thermoregulatory mechanisms. His finding was partially confirmed in the present study when Subject 5 continued to self regulate even though she was chilled and shivering.

Recall from the discussion following Subject 2 that neither he nor subject 6 was able to maintain voluntary self regulation following the onset of whole body chilling. The writer is unable to suggest any reason for the apparent differential ability, between subjects, to maintain

voluntary handwarming while thermally stressed.

There is an urgent need to resolve this issue before voluntary handwarming can be widely used to combat cold effects. Safety devices or procedures must be developed to insure that subjects do not continue to radiate heat into the environment when that heat is needed to preserve core temperature. For research purposes and with small selected samples it is probably sufficient to warn subjects to limit voluntary handwarming at very cold temperatures and to inhibit warming in the event of noticable organismic thermal stress.

5.4.3 The Need For Applied Research

This study has presented clear and unequivocal evidence that cold-induced impairment of hand function may be reduced without the use of gloves or other insulative devices. This finding has the potential to extend bare handed work and play activities intc temperature ranges where bare hand tasks were previously impossible, or achieveable only with difficulty. In addition, the use of voluntary handwarming has the potential to reduce the incidence of both direct cold injury and mechanical injury caused by numbed and stiffened hands. Although the treatment developed and reported in this thesis has the potential to make a substantial contribution one must be cautious not to overextend the data.

Certainly, a program of applied research is needed

prior to any attempt at widespread application. A possible program leading toward widespread application could be described as follows.

Phase one would involve refinement of the treatment package including a complete component analysis and the subsequent development of an efficient procedure designed to treat both hands at the same time. Phase one would enable rapid and inexpensive training of large numbers of experimental volunteers.

Phase two would examine and minimize the adverse interactive effects of treatment with conditions commonly found in the work place. These conditions could include the effects of consumables such as food, tobacco, coffee, tea, alcohol, and other drugs as well as physical and emotional states. Phase two would also examine and optimize procedures which could enhance or diversify the treatment. For example, this could involve combining or alternating treatment with the use of gloves or external heat sources. (The very rapid rewarming time found on all treated subjects in the present study suggests that treatment could be extended substantially by occasionally inserting the hands into a warm pocket or pouch and bringing them quickly back to a normal temperature.)

Phase three would investigate the effects of the experimental treatment on hand efficiency over a wide spectrum of temperatures, wind speeds, and humidities. The end product of phase three would be a series of charts

showing the thermal expense to the subject of exposure under differing conditions. That is, safe exposure times could be given for different environmental conditions.

Phase four would be a sequence of field experiments, using actual workers, to determine the generalization and transfer of laboratory techniques into field conditions.

Phase five would be the construction and validation of a non-technical training package which could be used in field settings by trainers with little or no teaching or technical training.

5.4.4 Related Research

This study suggests a number of possibilities for further research relevant to the biofeedback field. First, there is some tentative evidence to suggest that the classical-operant overlap procedure may produce different effects from biofeedback alone. For example, training in this study was very rapid with large temperature increases but the effect was bounded anatomically by the area of application of the conditioned stimulus (part way up the back of the hand). This suggests the possibility that a classical conditioning paradigm could be used both to establish rapid control of the target response paramaters as well as to increase effect magnitudes in temperature training and other physiological modalities.

Second, this study suggests the possibility of an alternate line of inquiry into the biofeedback treatment of

migrane and Raynaud's disease. For example, the present technique produced very rapid training, but will it work on migrane and Raynauds patients? Further, will classical conditioning , which requires less than one hours training, work alone to interupt migrane or Raynauds episodes.

5.4.5 Summary

The prolonged exposure of hands to cold environments leads to substantial cold pain and severe deterioration of manual dexterity, finger dexterity, hand strength, and tactile sensitivity. This study taught volunteers to warm their hands at -8 *C and measured the effect on these five hand efficiency variables. The subjects in this study were eight male and female non-smoking adult volunteers. All research was conducted in a cold chamber during the warm summer months to eliminate seasonal factors.

A combined multiple baseline/ABA single subject design with multiple replications was used. Each subject's hand performance was obtained for both hands both in the warm and in the cold. One hand was trained and both hands were re-tested in the cold. The second hand was trained and both hands were re-tested in the cold. Finally, the subject inhibited warming while in the cold (treatment removal) and both hand were tested again.

The treatment itself used biofeedback instrumentation to extend and enlarge previously classically conditioned vasodilative episodes. The procedure was found to be

effective for bringing about temperature changes in the cold. Large treatment effects were found on all hand efficiency measures. The results suggest wide workplace and theory implications.

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APPENDIX A

MAJOR VESSELS

The hand is supplied with blood through the brachial artery which, from the elbow on, becomes the radial and ulnar arteries. Both arteries lie deep along the volar forearm. As they cross the wrist one branch of each artery (dorsal ulnar carpal, and dorsal radial carpal) loops up and joins (anastomoses) with its counterpart to form an arch across the dorsum of the wrist. Four branches (dorsal metacarpal arteries) leave this arch, run distally through the metacarpal interspaces and branch again at the knuckles to provide digital arteries along the adjacent surfaces of the four fingers. A fifth branch of the dorsal arch (first dorsal metacarpal) supplies adjacent sides of the thumb and index finger.

Back on the volar side of the wrist, the radial artery approaches the thumb while the main trunk of the ulnar artery ,leads toward the little finger. A superficial branch of the ulnar artery travels across the center of the palm roughly under the proximal palmar flexion crease to join with the volar radial artery thus forming the superficial volar arch. This arch gives off common volar digital arteries which cross the palm to the web spaces of the fingers and there divide into volar digital arteries supplying the adjacent sides of the four fingers.

The deep volar branch of the ulnar artery travels across the proximal boundary of the palm about 4.5 cm

proximal from the superficial arch, loops under the thumb and joins the dorsal arch. The result is a deep second arch on the palm known as the deep volar arch. The deep volar arch gives off five volar branches. Three of these, the volar metacarpal arteries, anastomose with the common volar digital branches of the superficial arch. The fourth, (radialis indicus) supplies the radial volar side of the index finger. The fifth, (princeps pollicis) runs down the volar side of the thumb, branches just before reaching the distal flexion crease and supplies the distal volar portion of the thumb.

All these arteries continue to divide and sub-divide into progressively smaller vessels throughout the hand tissue. The very smallest arteries, or arterioles, deliver blood into the capillaries, tiny vessels about 1/100 mm in diameter. The capillaries, unlike veins and arteries, are permeable so that all exchange of materials between blood and tissue takes place in and around the capillaries.

The overall capacity of the body's capillaries, should they be open at one time, far exceeds the bodys supply of blood. As a result, some form of selective control is necessary to ensure a sufficient and continuous supply of blood to the body core. The primary criterion for determining the volume of blood circulating through most organs and subcutaneous tissues is the demand for oxygen and carbon dioxide exchange. In the skin, however, the primary criterion for determining blood flow is blood pressure and

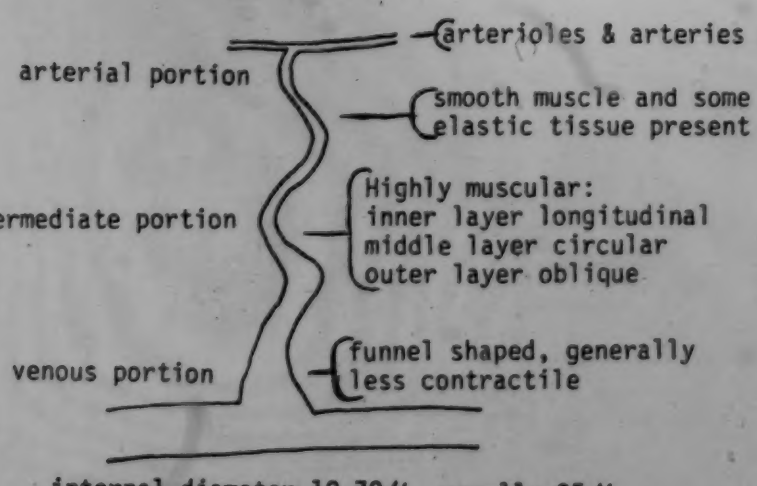
temperature regulation. The specialized sturctures and controls of the skin in relation to temperature regulation are discussed in the body of the thesis as well as in Appendix B.

The venous return system of the hand does not parallel the arterial system as is usual in the rest of the body. Instead, venous return is through large veins on the dorsum of the hand and wrist. Considerable evolutionary advantage accrues to a dorsal venous return system in that sustained hand grip does not occlude dorsal venous return as it would a volar return system.

APPENDIX B

MICRO-CIRCULATION

This appendix provides a more extensive description of the arteriovenous anastomoses (AVA) than has been provided in the thesis body. The AVA is a direct, highly innervated, elastic connection between an arteriole (or artery up to 100 microns) and a vein with an external diameter between 50 and 100 microns. The figure below presents a diagramatic description of the vascular component of an AVA channel. In vivo, the AVA may have multiple channels and may be straight, curved or convoluted. The vascular component is encased in a haze of adrenergically mediated sympathetic nervous fibers. In addition, the vascular component dilates in response to cholinergins including accetylcholine and acetyl-B-methylcholine which appears to indicate sympathetic cholinergic vasodilative innervation.



(from Nelms, 1963)

APPENDIX C

CONTROL OF THE MICRO-CIRCULATION

IN CIVD

Historically, there has not been widespread agreement on the trigger and control mechanisms of local, hand, CIVD. Initially, Lewis (1930) believed that an axon reflex was involved because he found unimpaired CIVD following sympathectomy but not following peripheral nerve degeneration. Kramer and Schultz (1948) concurred following their failure to find CIVD in novacaine blocked fingertips. Greenfield, Shepperd, and Whelan (1952) however, were unable to replicate the findings of Kramer and Schultz.

Hilton and Lewis (1955) provided evidence for the formation of a chemical vasodilator substance in the human salivary gland. Silva, Beraldo, & Rosenfeld (1949) manipulated snake venom to synthesize Bradykinin, the most potent vasodilator yet known. Both of these chemical vasodilator studies stimulated a flood of related research (Hilton, 1962).

By 1962 the consensus of opinion held that local vasodilation occurs from some chemical stimulus (a plasma kinin) produced by cellular activity in the tissue concerned, which diffuses through the tissue fluid to act on the smooth muscles of the precapillary arterioles (Hilton, 1962). In addition, Hilton (1962) suggested the possibility

of a similar effect on the larger arteries throughout the organ or tissue concerned. These findings do not appear to have been extended to the AVA and are not restricted solely to the skin.

Fox and Hilton (1958) identified the specific sweat gland related production of a vasodilator plasma kinin in response to heat. The production of this, or a parallel kinin in response to cold has not been experimentally verified at this time.

As discussed above, the specific control menchanisms of CIVD are not clear. THe earlier onset and increased reactivity of CIVD which mark hand habituation may be intrinsic to the CIVD mechanism. On the other hand, CIVD adaptation may occur partly or wholly as the result of other local tissue adaptations as discused in the text of the thesis.

APPENDIX D

ANNOVA TABLES FOR COMBINED HANDS

Table A 1: Manual Dexterity

Source of Variation	SS	DF	MS	F
Between People	242.1	11	22.0	
Within People	529.3	36	14.7	
Treatments	399.2	3	133	33.8
Residual	130.0	33	3.94	
Total	771.3	47		

Probability of F = 0.00000

Tukey comparison between means

		1	2	4	5
	Means	34.7	33.1	29.8	27.3
2	27.25	7.41*	5.83*	2.50*	0.0
5	29.75	4.91*	3.33*	0.0	
4	33.08	1.58	0.0		
1	34.67	0.0			

* indicates significance at $p < .05$ or better
(critical difference at $p < .05$ is 2.20)
(critical difference at $p < .01$ is 2.80)

Table A 2: Finger Dexterity

Source of Variation	SS	DF	MS	F
Between People	65.0	11	5.9	
Within People	348.1	36	9.8	
Treatments	277.0	3	92.3	42.8
Residual	71.2	33	2.2	
Total	413.1	47		

Probability of F = 0.00000

Tukey comparison between means

		1	4	5	2
	Means	12.4	10.6	8.3	6.0
2	6.04	6.36*	4.58*	2.21*	0.0
5	8.25	4.15*	2.38*	0.0	
4	10.63	1.78*	0.0		
1	12.40	0.0			

* indicates significance at $p < .05$ or better
(critical difference at $p < .05$ is 1.63)
(critical difference at $p < .01$ is 2.04)

Table A 3: Hand Strength

Source of Variation	SS	DF	MS	F
Between People	9,472	11	861	
Within People	6,275	36	174	
Treatments	3,345	3	1,115	12.6
Residual	2,929	33	88.7	
Total	15,747	47		

Probability of F = 0.00001

Tukey comparison between means

		1	4	5	2
	Means	92.5	81.8	75.1	70.3
2	70.25	22.3*	11.6*	4.83	0.0
5	75.08	17.4*	6.75	0.0	
4	81.83	10.7*	0.0		
1	92.50	0.0			

* indicates significance at $p < .05$ or better
(critical difference at $p < .05$ is 10.44)
(critical difference at $p < .01$ is 13.05)

Table A 4: Tactile Sensitivity

Source of Variation	SS	DF	MS	F
Between People	68.4	11	6.22	
Within People	78.9	36	2.19	
Treatments	25.9	3	8.63	5.37
Residual	53.0	33	1.61	
Total	147.3	47		

Probability of F = 0.0040

Tukey comparison between means

		2	5	4	1
	Means	3.53	2.88	1.88	1.74
1	1.742	1.78*	1.13	.133	0.0
4	1.875	1.65*	1.00	0.0	
5	2.875	.650	0.0		
2	3.525	0.0			

* indicates significance at $p < .05$ or better
(critical difference at $p < .05$ is 1.40)
(critical difference at $p < .01$ is 1.76)

Table A 5: Pain

Source of Variation	SS	DF	MS	F
Between People	8732	11	794	
Within People	38137	36	1059	
Treatments	32855	3	10951	68.4
Residual	5281	33	160	
Total	46870	47		

Probability of F = 0.00000

Tukey comparison between means

		2	5	4	1
	Means	63.3	62.9	31.7	00.0
1	00.00	63.3	62.9	31.7	0.0
4	31.67	31.67	31.25	0.0	
5	62.92	0.42	0.0		
2	63.33	0.0			

* indicates significance at p < .05 or better
(critical difference at p < .01 is 14.24)
(critical difference at p < .05 is 17.53)

APPENDIX E

RAW DATA

		Manual Dexterity	Finger Dexterity	Hand Strength	Tactile Sensitivity	Pain
Colin	111	33 25 33 32 28	115 60 115 105 75	100 90 90 100 95	22 32 18 18 29	03 01 01 20
	122	32 25 29 32 29	110 40 60 100 70	100 85 85 95 90	20 27 22 22 25	03 01 5 8 20
Henry	212	34 19 30 31 29	135 5 80 80 80	111 35 80 75 70	18 99 66 31 95	09 56 38 58 5
	221	35 23 34 35 30	135 25 75 115 90	105 65 95 95 90	20 29 21 20 21	08 55 55 07 5
Dennis	311	34 28 33 36 31	135 75 105 120 90	100 87 87 87 70	18 26 17 20 30	05 53 53 58 0
	322	33 28 31 32 30	125 85 80 115 95	105 75 90 89 72	23 26 22 21 25	05 54 02 56 0
Brian	412	38 34 40 39 33	118 85 125 120 95	95 90 92 92 85	16 33 21 16 20	07 01 01 07 0
	421	39 33 36 36 32	130 110 55 105 95	100 100 100 95 90	15 67 29 17 21	07 02 01 5 70
Penny	511	36 28 29 29 28	135 75 120 120 85	76 45 55 60 56	9 16 10 9 12	07 07 03 57 5
	522	32 28 28 28 28	125 50 55 90 80	70 40 50 54 50	9 14 18 10 11	07 07 03 57 5
Linda	612	36 28 34 35 30	105 50 95 100 55	72 64 68 68 65	17 28 18 20 30	06 54 03 56 5
	621	34 28 29 32 29	120 65 70 105 80	76 67 67 72 68	22 26 23 21 26	06 54 53 56 0

Dominant=1; Non-dominant=2

1st treated hand=1; 2nd treated=2

Subject number